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SHUTTLE

FINAL REPORT

SHUTTLE CRYOGENICS SUPPLY SYSTEM OPTIMIZATION STUDY

VOLUME VI

APPENDIXES

CONTRACT NAS9-11330

Prepared for Manned Spacecraft Center
by
Manned Space Programs, Space Systems Division

LOCKHEED MISSILES & SPACE COMPANY. INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

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FOREWORD

This Final Report provides the results obtained in the Shuttle Cryogenics Supply System Optimization Study, NAS 9-11330, performed by Lockheed Missiles & Space Company (LMSC) under contract to the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas. The study was under the technical direction of Mr. T. L. Davies, Cryogenics Section of the Power Generation Branch, Propulsion and Power Division. Technical effort producing these results was performed in the period from October 1970 to June 1973.

The Final Report is published in eleven volumes*:

Volume I	Executive Summary
Volume II, III, and IV	Technical Report
Volume VA-1 and VA-2	Math Model – Users Manual
Volume VB-1, VB-2, VB-3, and VB-4	Math Model – Programmers Manual
Volume VI	Appendixes

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*The Table of Contents for all volumes appears in Volume I only. Section 12 in Volume III contains the List of References for all volumes.

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TABLES

Appendix A

AUXILIARY POWER UNIT PARAMETRIC DATA

Parametric data were produced on the Auxiliary Power Units based upon information presented in the NASA technology contracts.

Parametric data depicting propellant flow-rate requirements of turbines in the horsepower ranges expected for the auxiliary power and orbit maneuver propulsion system applications are shown in Figures A-1 through A-16. Data are given for 100, 150, 200, 250, and 300 horsepower units showing fuel consumptions vs percent of rated horsepower over an output range of 20 to 100 percent of rated. The offrated performance characteristics have been linerarized between 20 and 100 percent of rated output from turbine designs provided by APU technology contractors.

For flexibility in future cryogenics supply system optimization studies, turbine parametric data have been generated over the range of turbine pressures, temperatures, and mixture ratios currently being considered for candidate systems. Data are given for maximum turbine inlet pressures of 900, 600, and 300 psia; turbine gas inlet temperatures of 1800° F, and 1600°F; and propellant mixture ratios of 0.5 and 1.0. Turbine propellant consumption has also been determined for sea level and altitude operating conditions for evaluation of duty cycle implications.

The turbine backpressure schedule used for the baseline turbine performance data is shown in Figure A-1. Exhaust system flow impedances, i.e., duct losses, heat-exchanger pressure drops, and exit-nozzle choking losses producing these pressures are suitable for integration tradeoff studies without adjustment in turbine propellant consumption due to pressure ratio effects.

Three basic turbine designs are represented in the parametric data, one for a 900 psia gas supply service, one for 600 psia service, and one for 300 psia service. The turbine design point of each is based upon optimization studies and results of the APU technology contractors. Because of APU duty

cycle effects, the optimum turbine design point is at low power (approximately 30 percent and intermediate altitudes (approximately 10,000 ft). Utilization of an optimum turbine design at the 100 percent horsepower output of the parametric data would reduce the turbine flow-rate at 100 percent horsepower indicated in Figures A-2 through A-13 by approximately 2 percent.

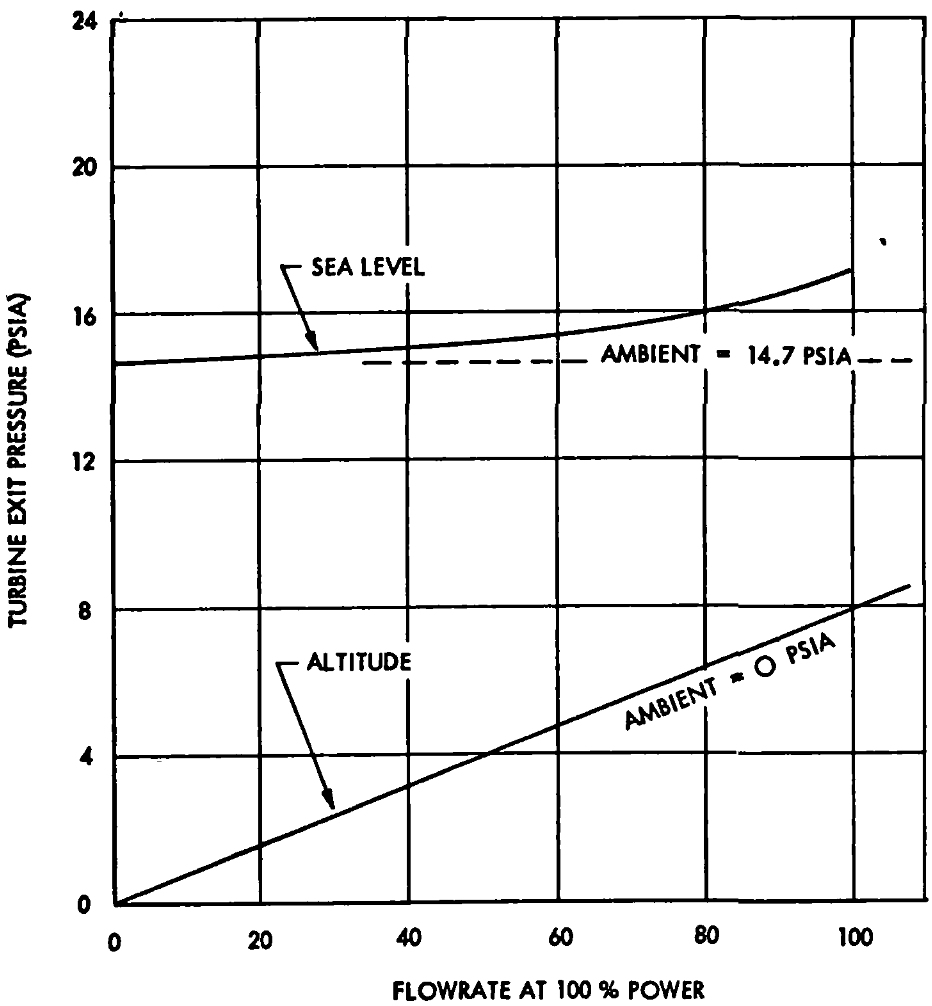


Fig. A-1 Turbine Performance Exhaust Pressure Vs Flowrate Pressure Modulation Control (Baseline Exhaust System Characteristics for Parametric Evaluations)

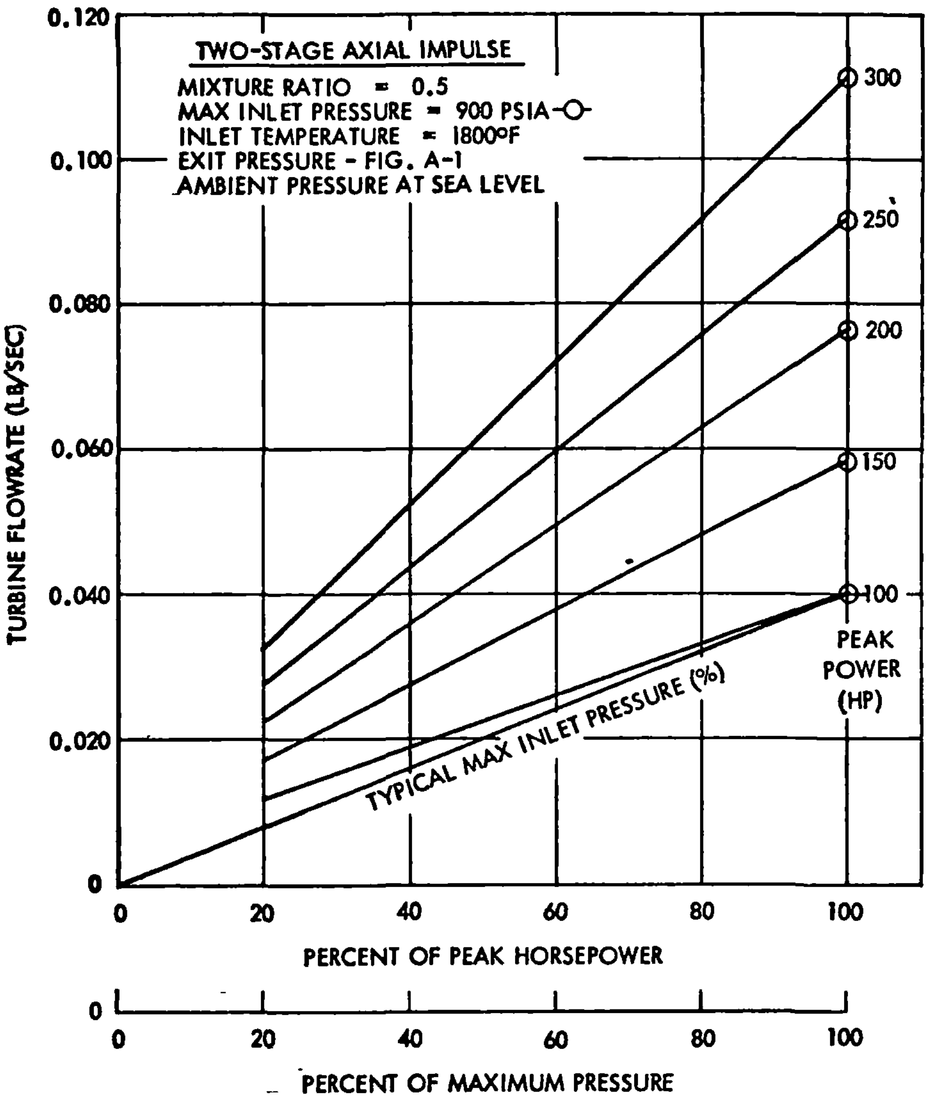


Fig. A-2 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

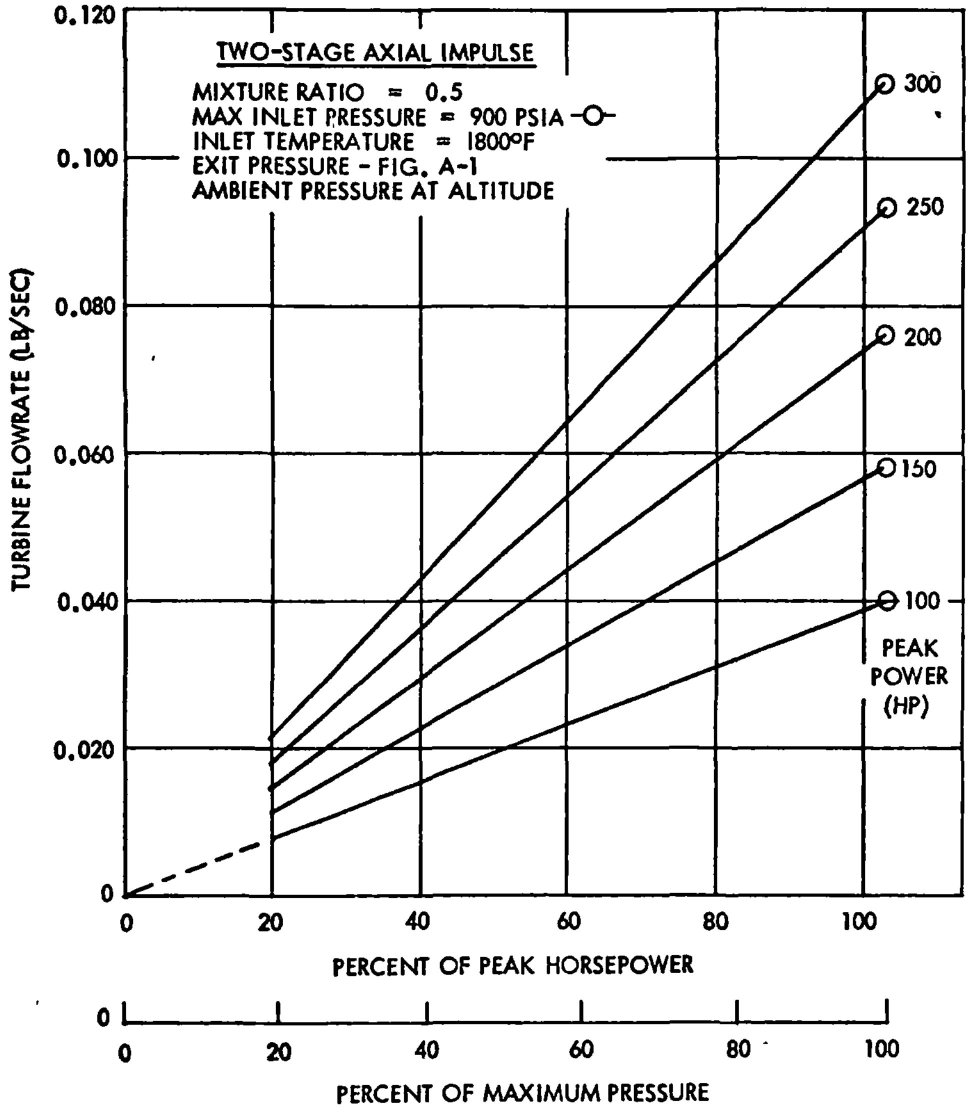


Fig. A-3 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

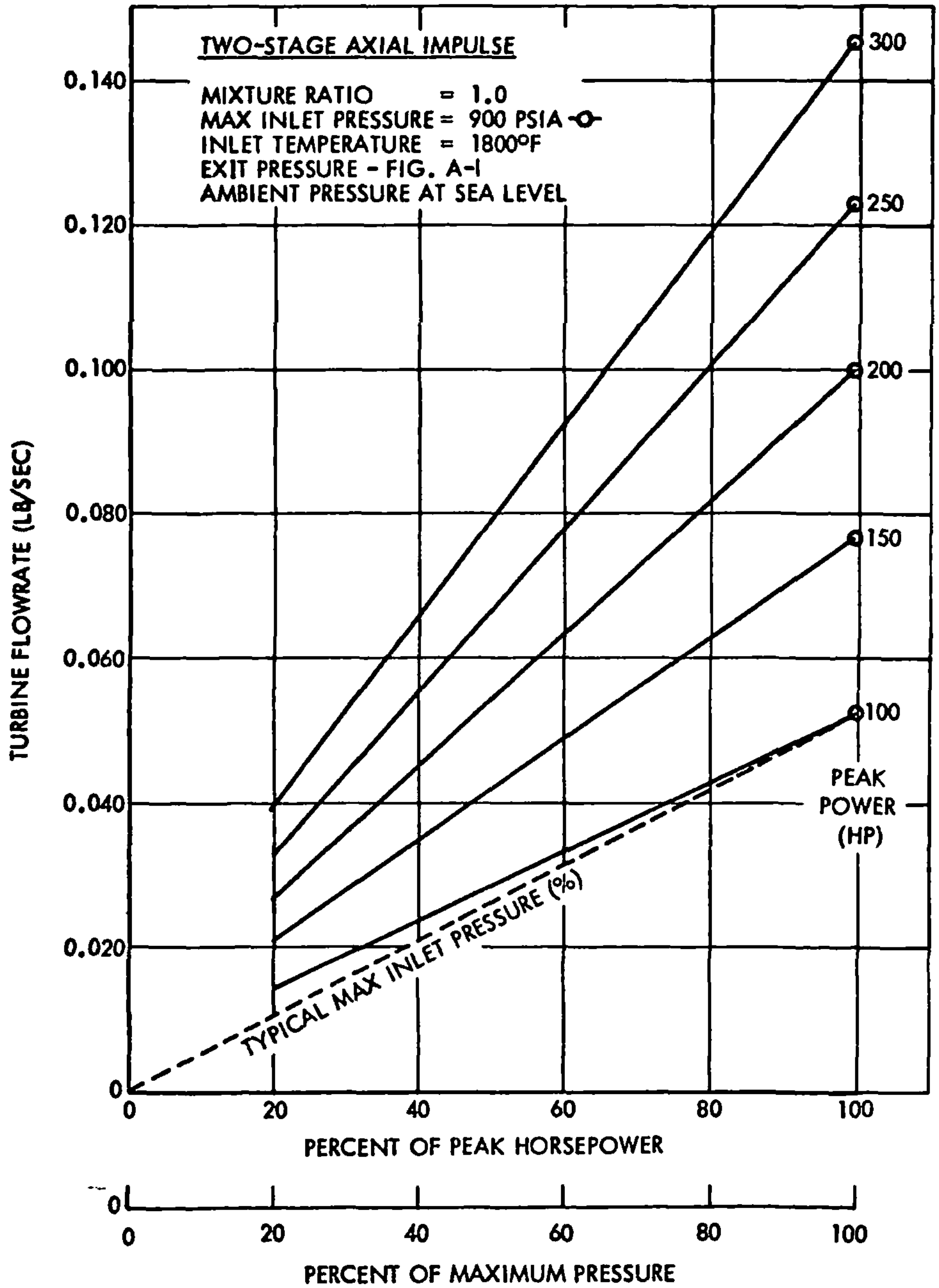


Fig. A-4 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

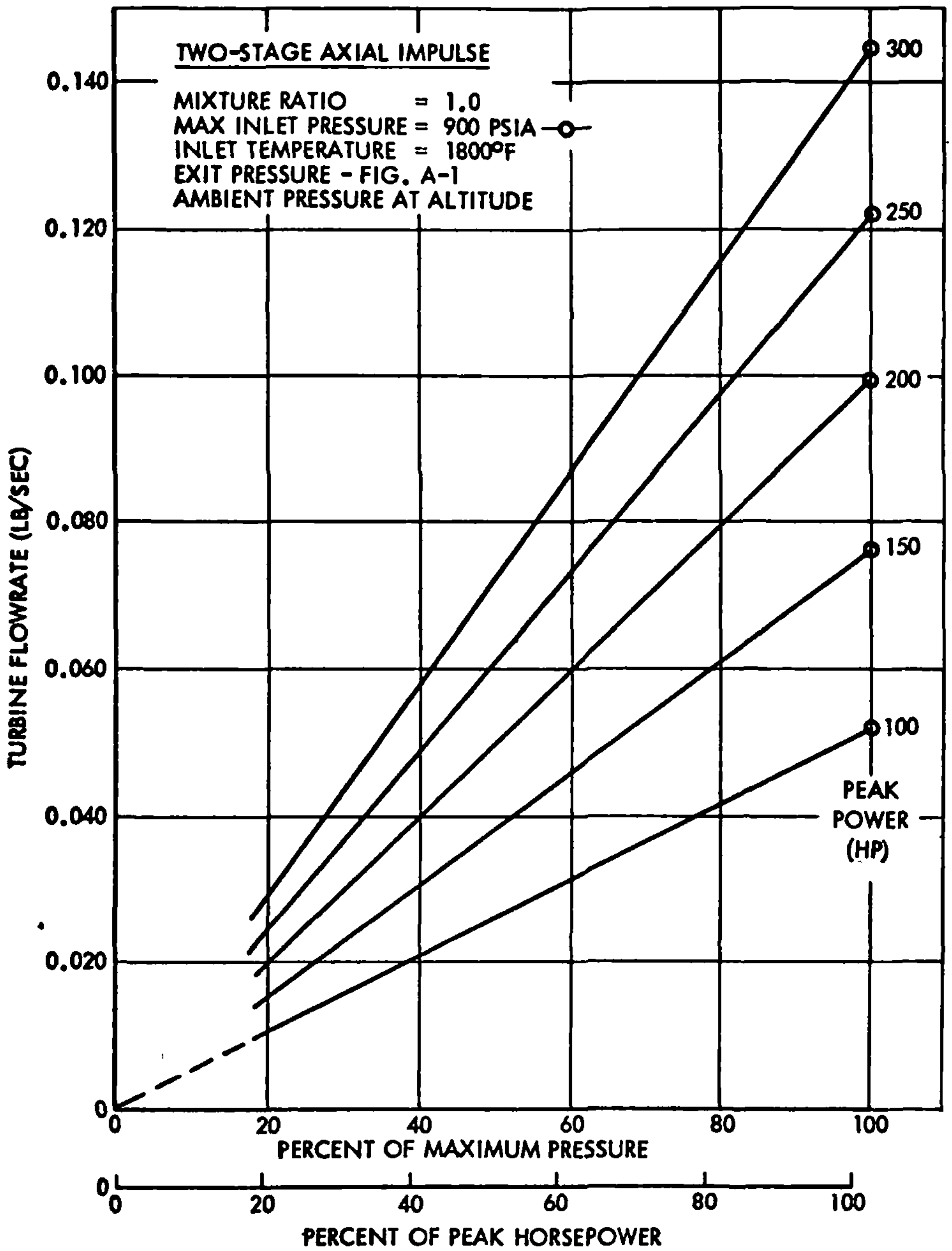


Fig. A-5 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

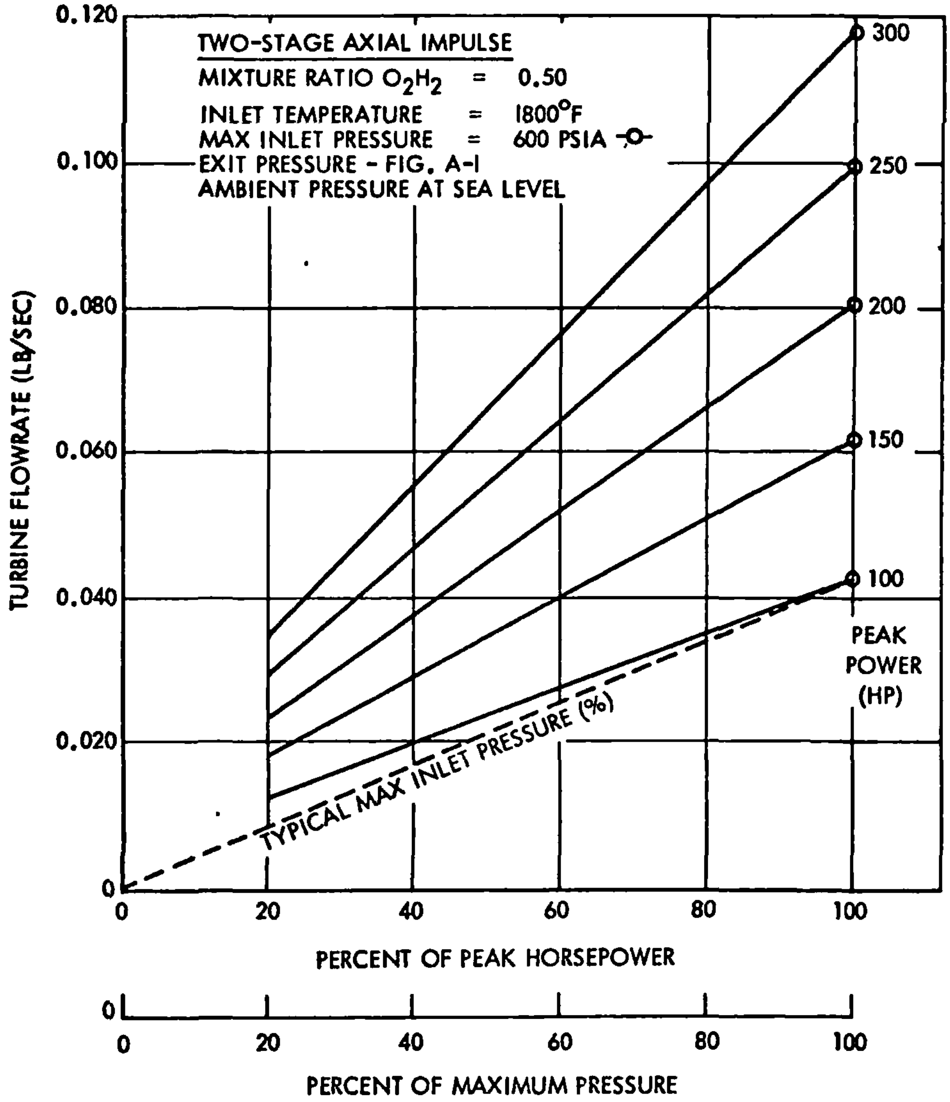


Fig. A-6 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

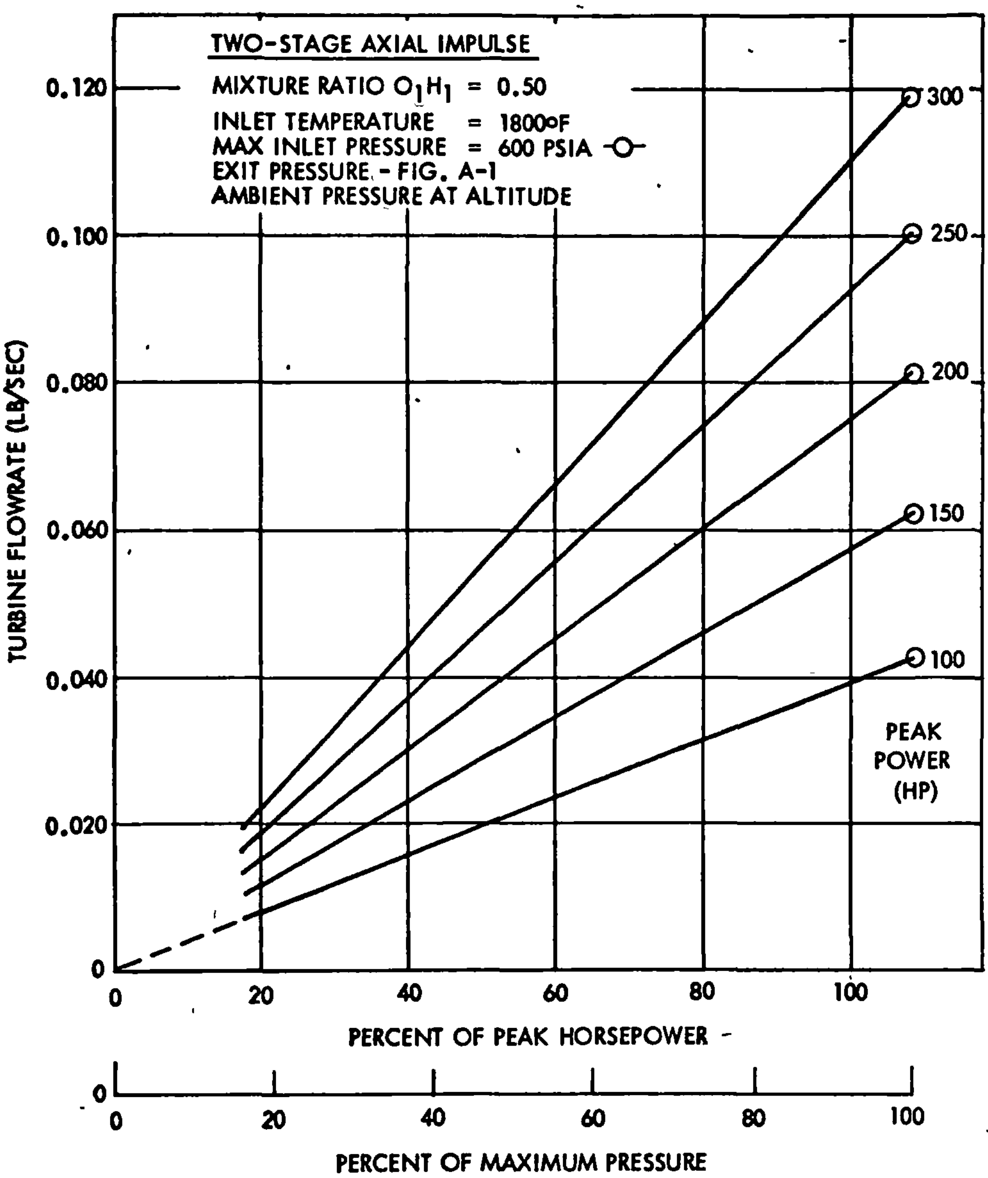


Fig. A-7 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

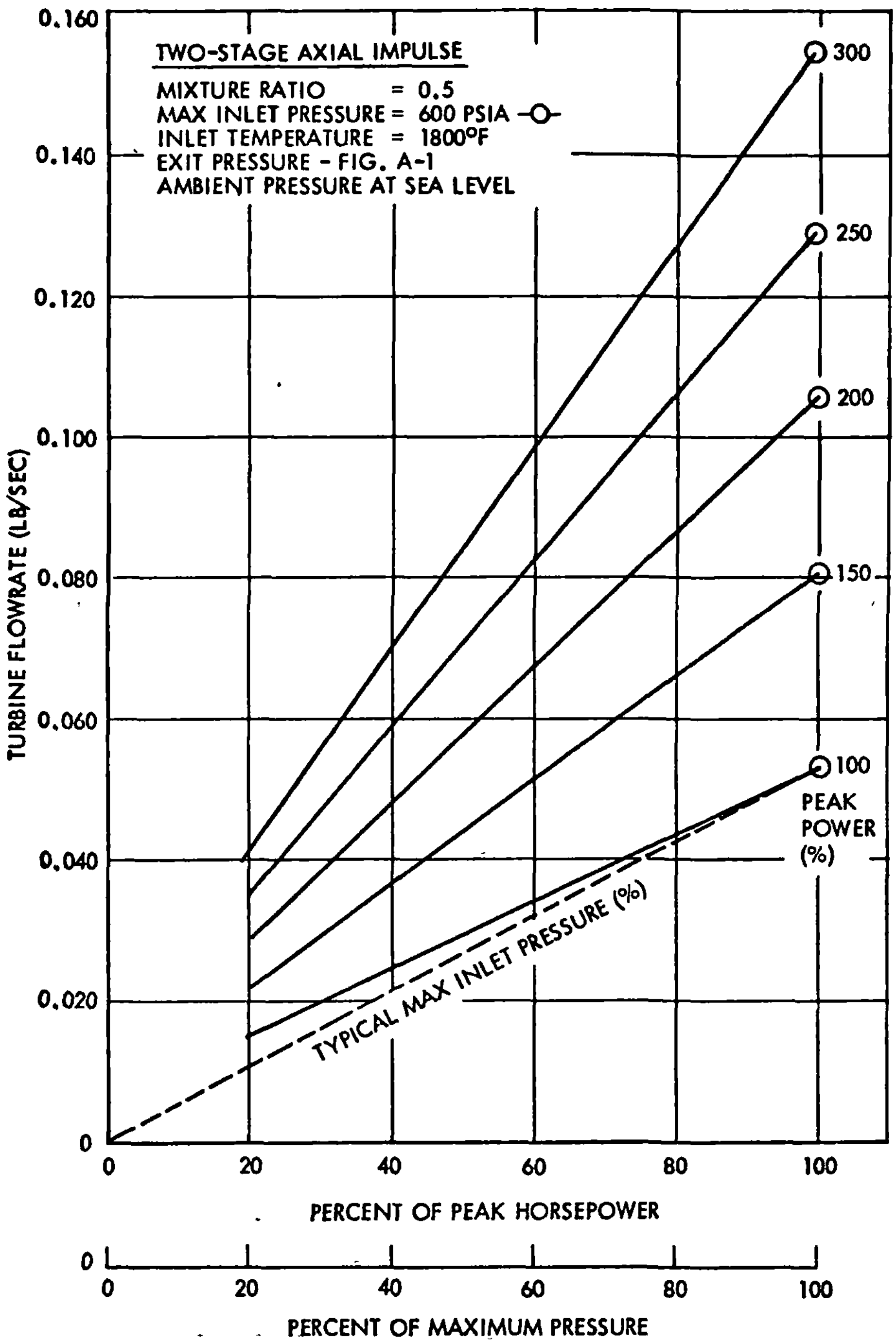


Fig. A-8 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

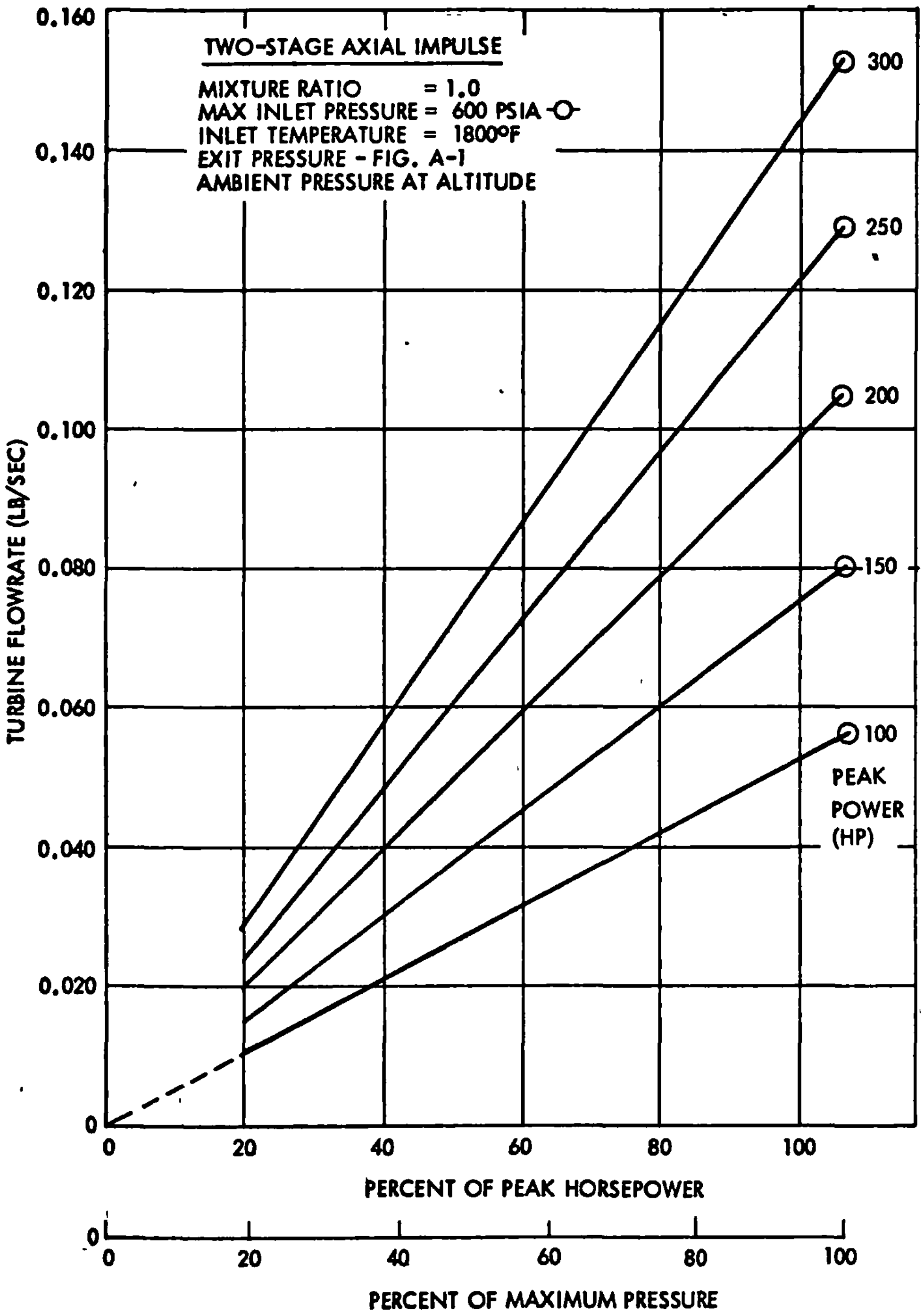


Fig. A-9 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

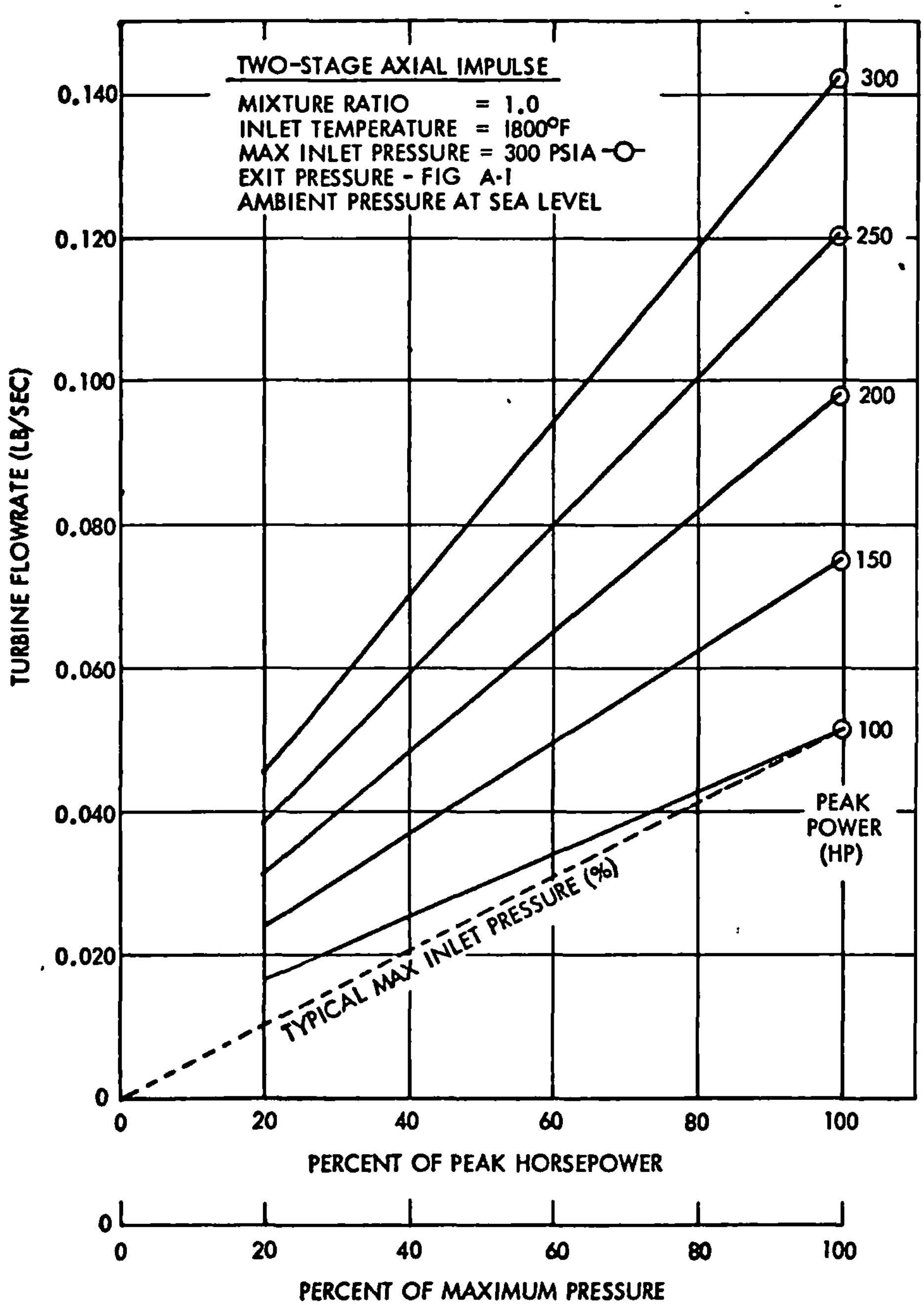


Fig. A-10 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

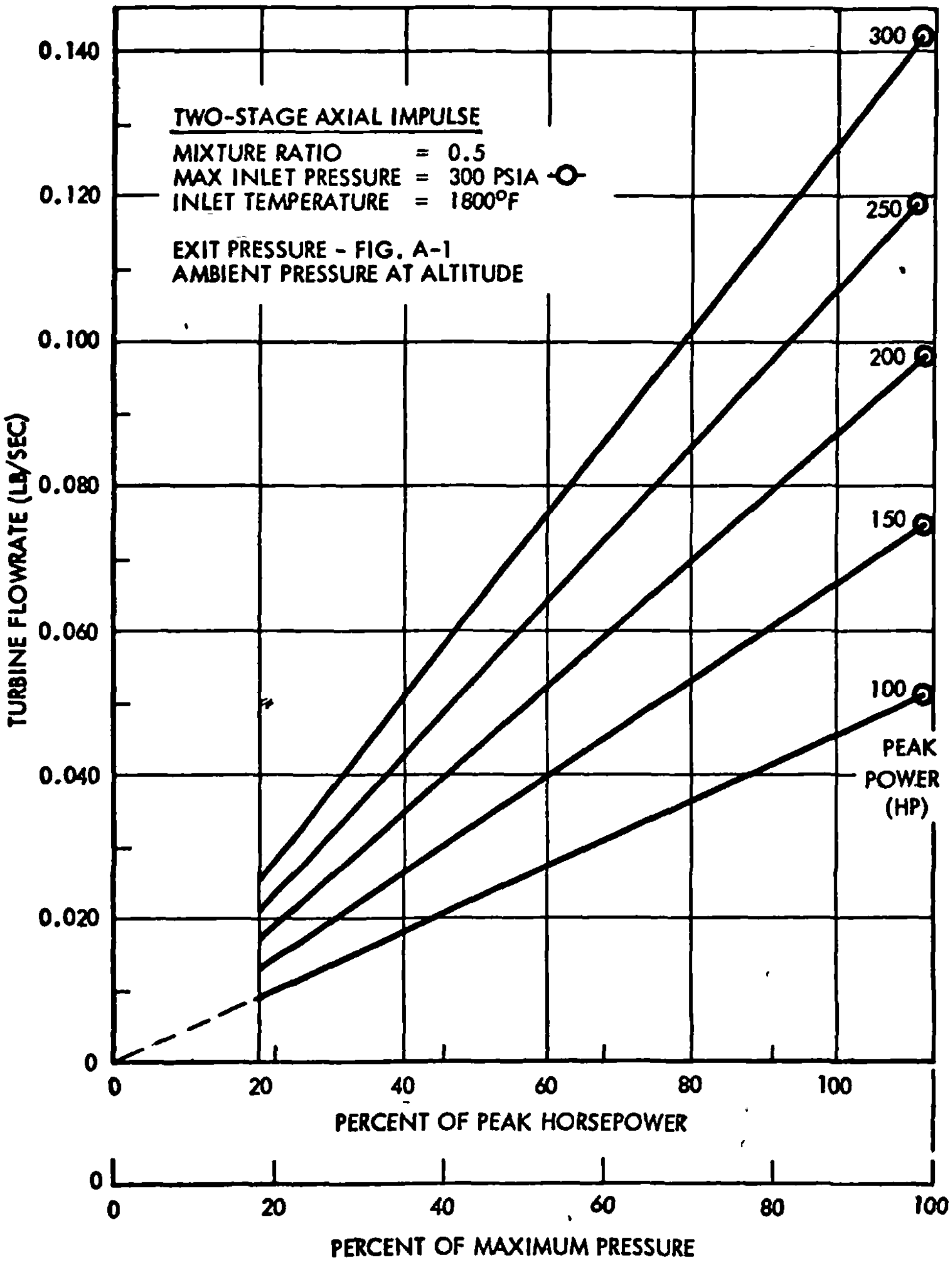


Fig. A-11 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

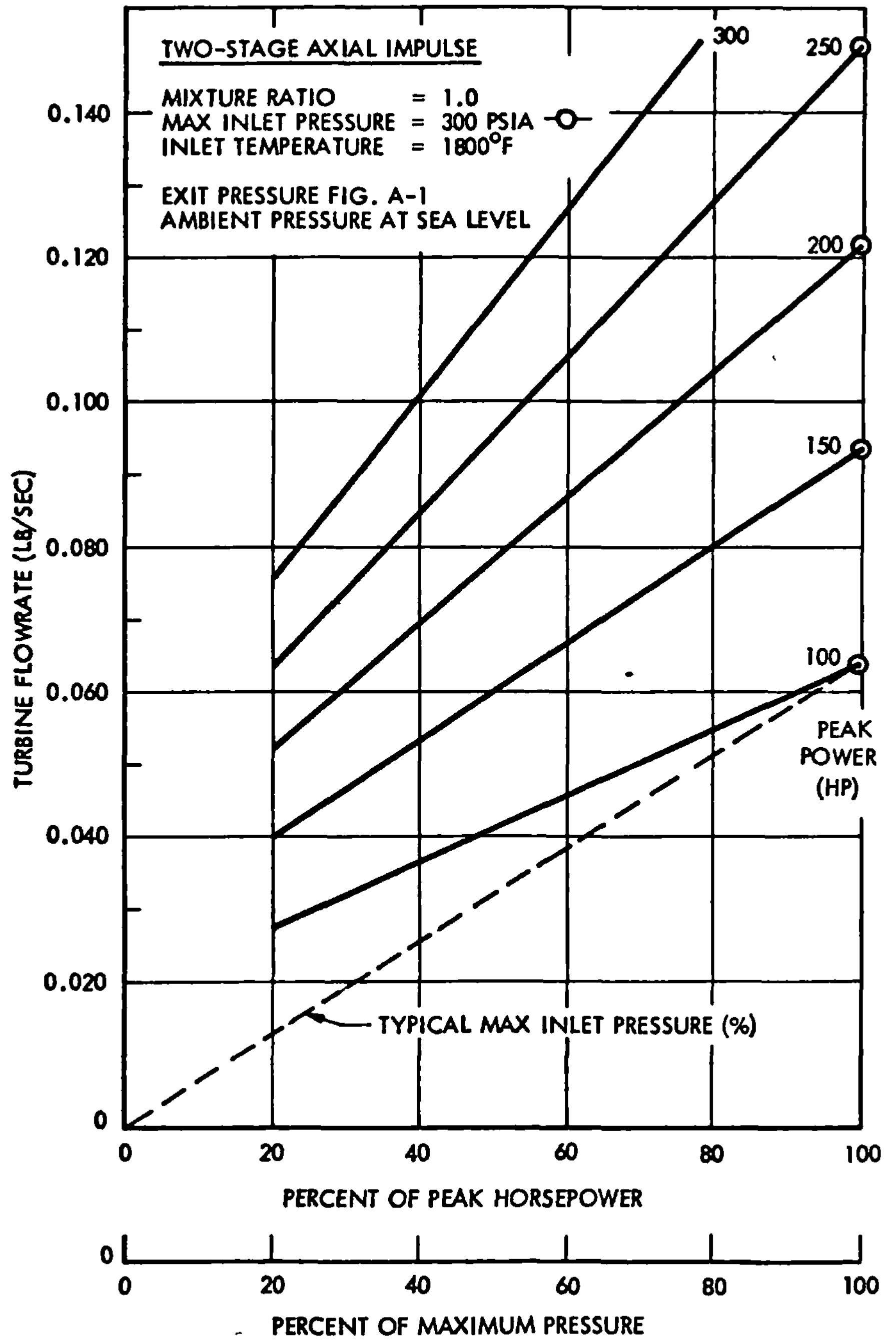


Fig. A-12 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)

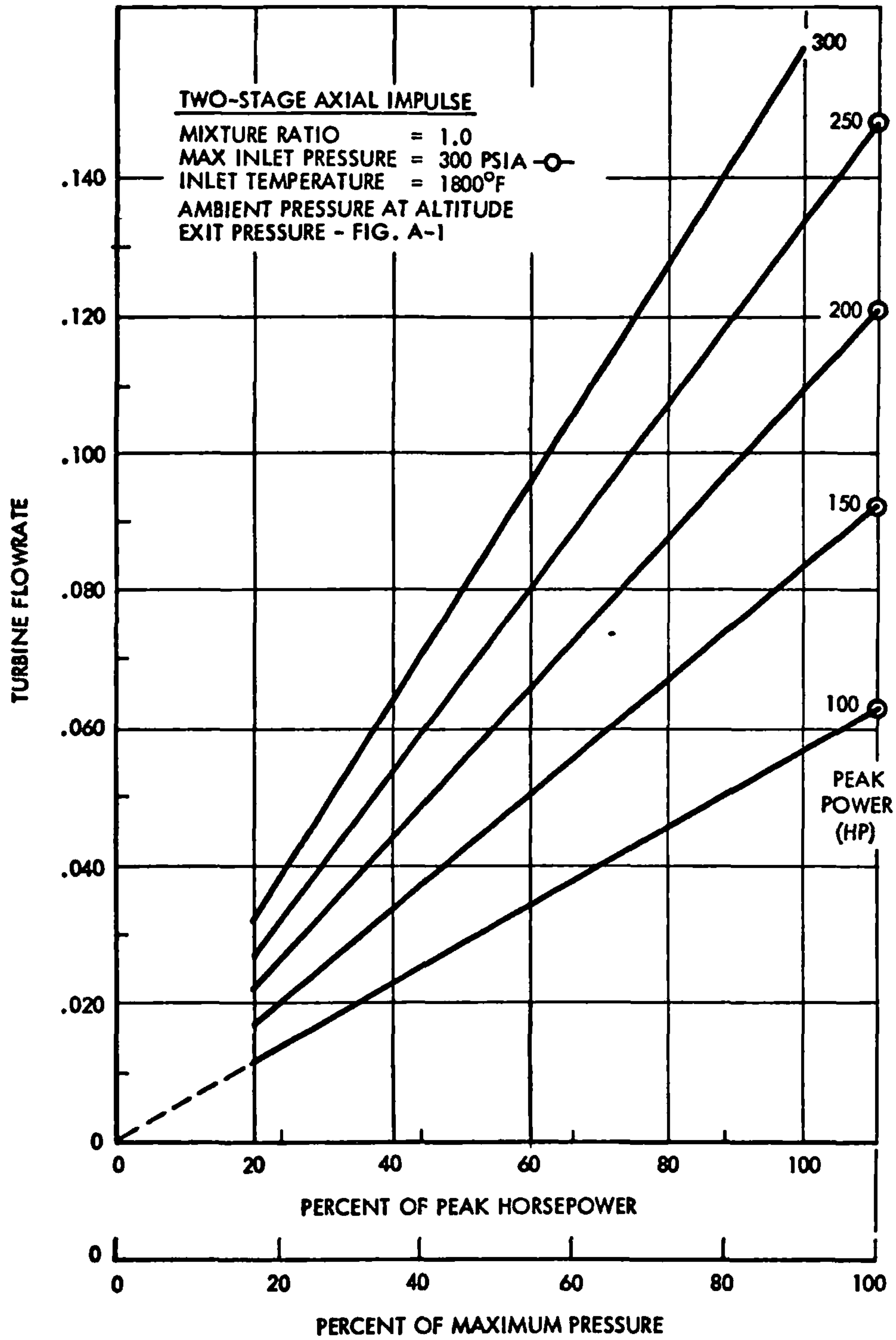
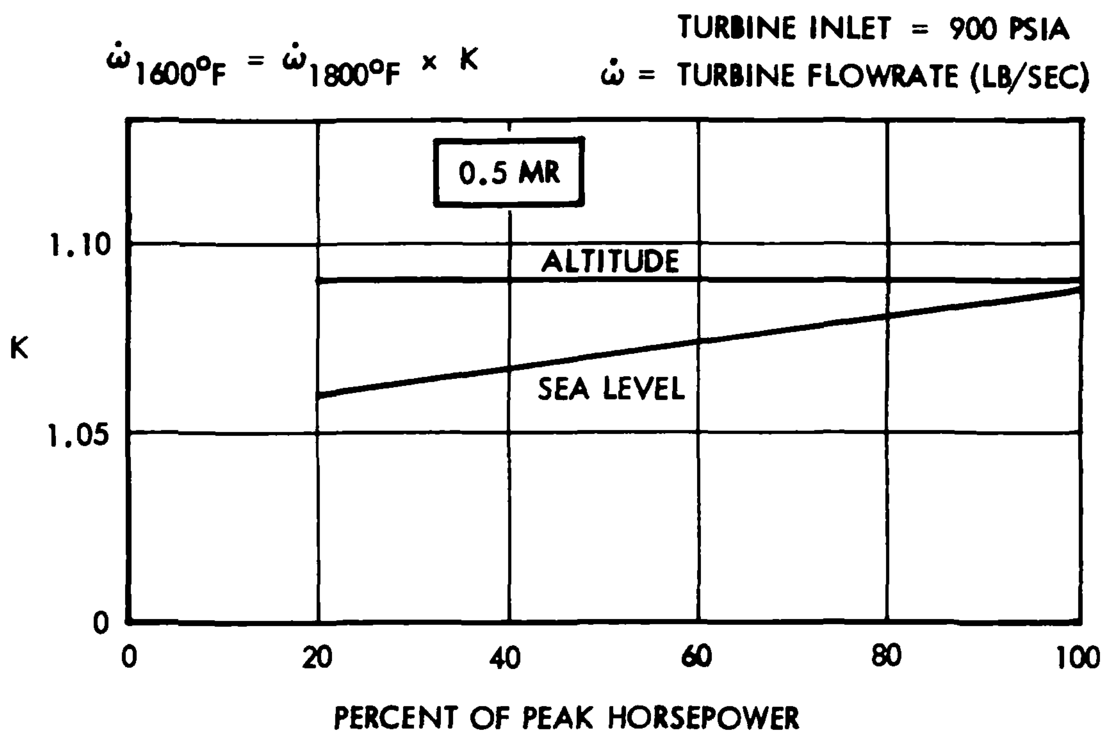


Fig. A-13 Turbine Performance Power Vs Flowrate (Pressure Modulation Control)



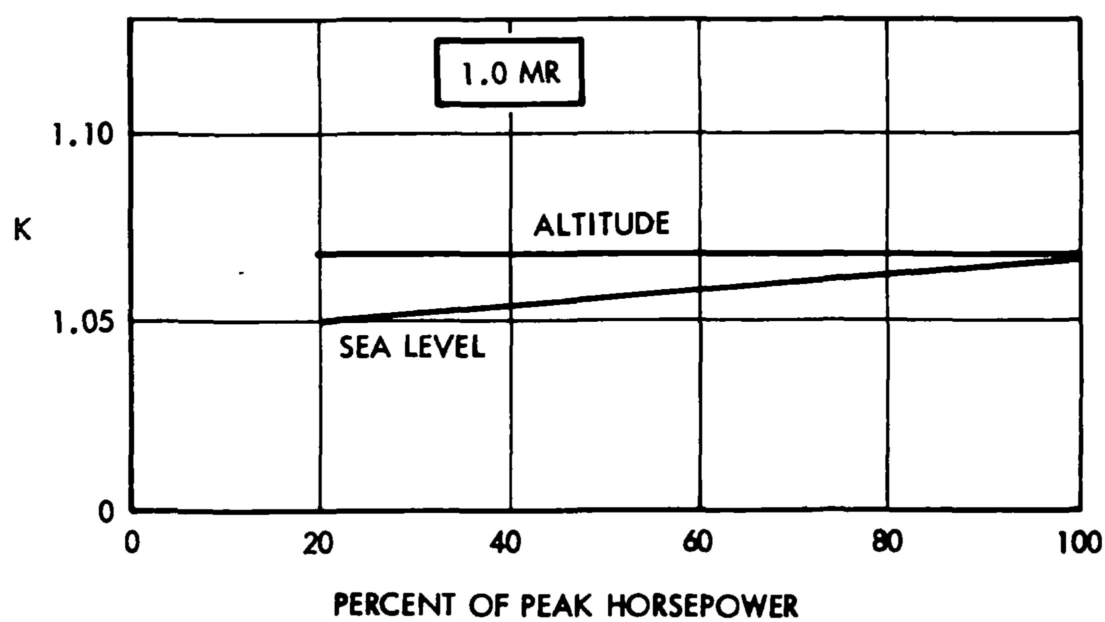


Fig. A-14 Gain Factor - Turbine Flowrate Turbine Inert Gas Temperature 1800°F to 1600°F

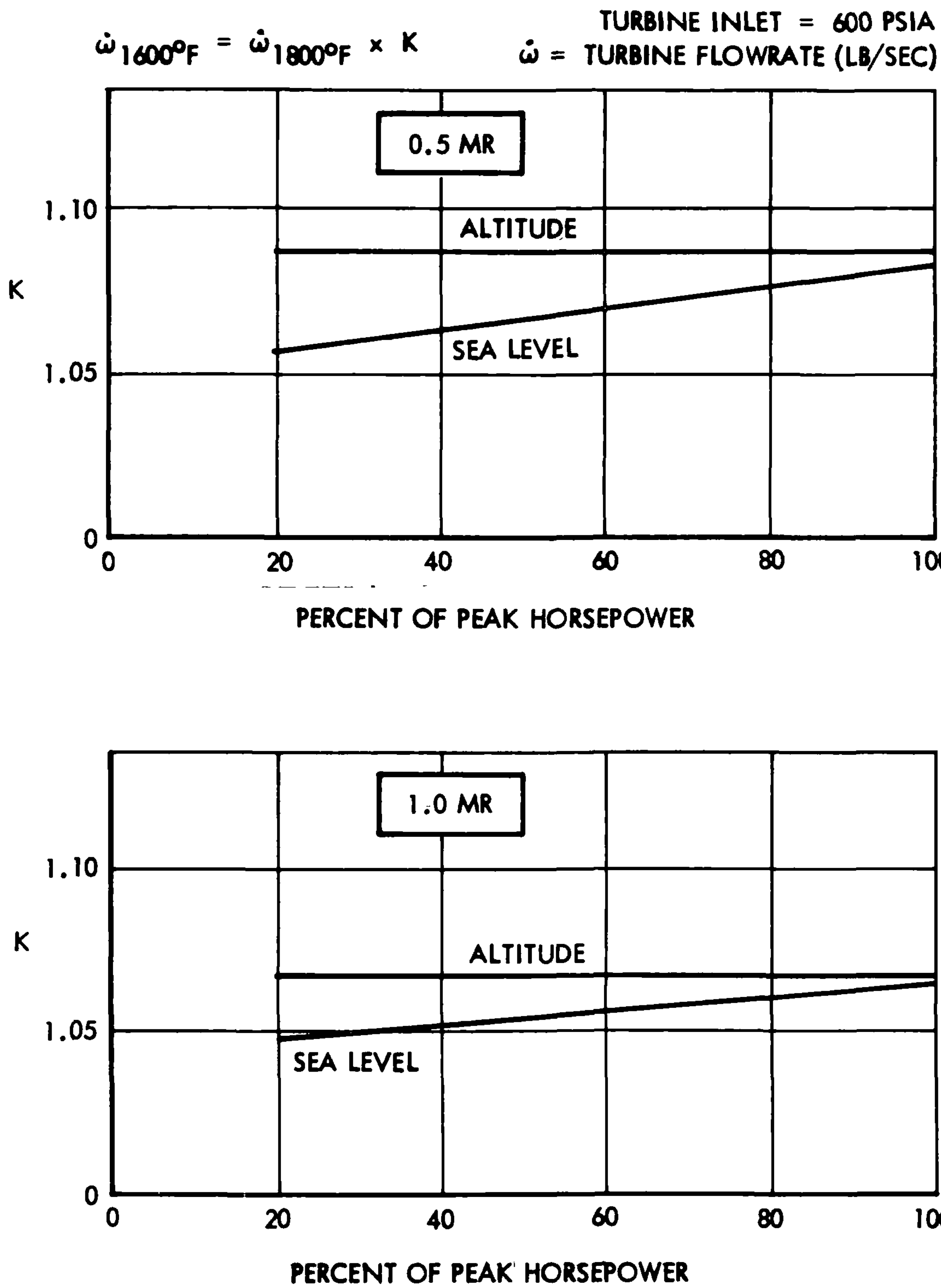


Fig. A-15 Gain Factor - Turbine Flowrate Turbine Inlet Gas Temperature 1800°F to 1600°F

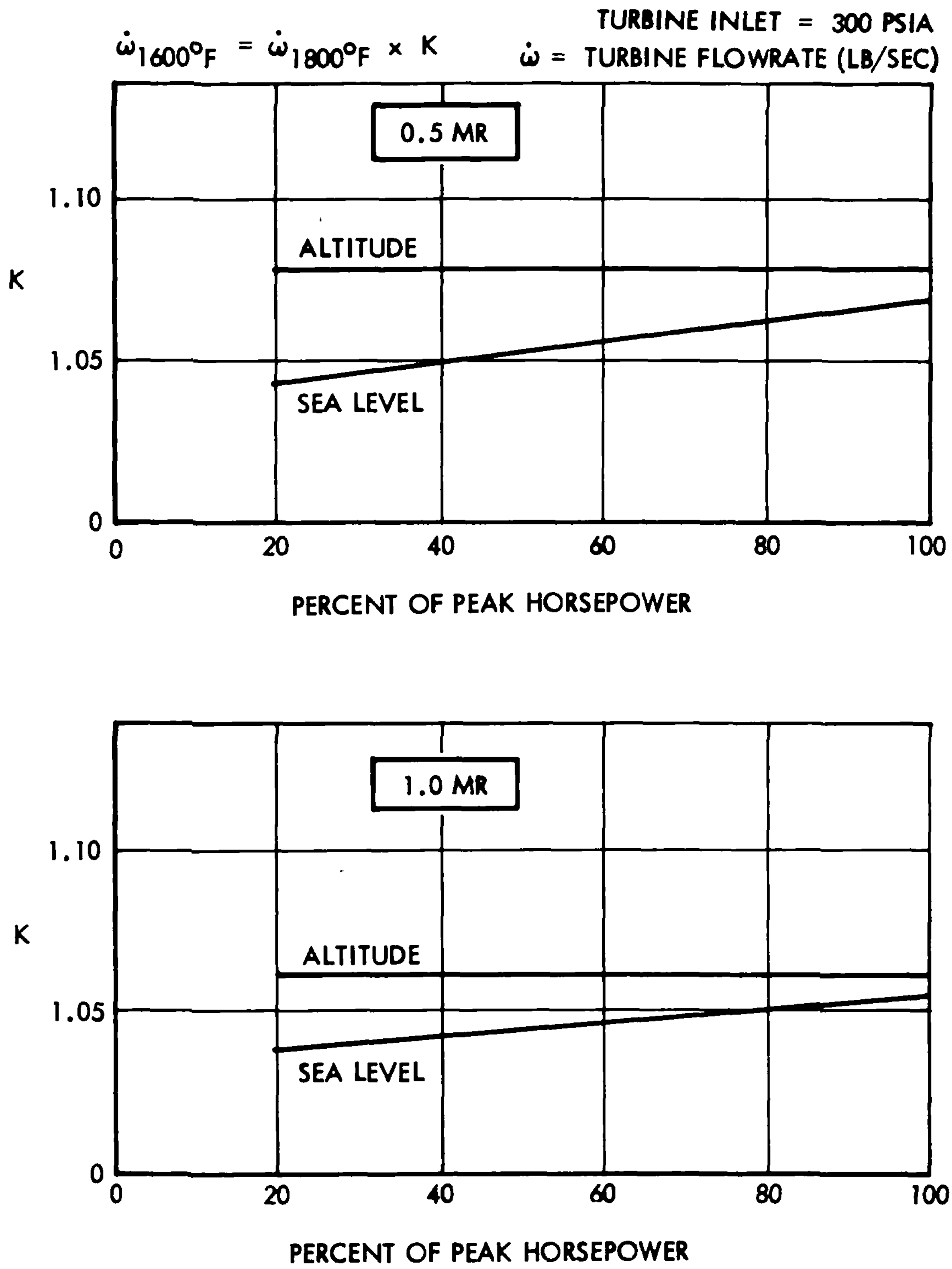


Fig. A-16 Gain Factor - Turbine Flowrate Turbine in Gas Temperature 1800°F to 1600°F

Appendix B

PROPELLANT ACQUISITION

This appendix provides a summary of propellant acquisition analyses conducted in the program. Propellant acquisition devices are essential to the operation of the Attitude Control Propulsion System, the Auxiliary Propulsion System, and any other supply utilizing liquid propellants and reactants under low gravity conditions.

Propellant Acquisition Requirements and Approach

The diagram in Figure B-1 illustrates in summary form the general technique applied to the design of propellant retention and acquisition systems and the factors that have important influence on the design. The propellant tankage for each system has been analyzed from the particular standpoint of the design of surface tension acquisition systems, and from this analysis and data organization design concepts have been formulated which in general meet the operation requirements of the particular tankage. These concepts are discussed after the following comments on the constraints that influence the designs.

Some general groundrules have been established which provide background for design decisions and provide guidance in areas of vehicle operation where no definite requirement presently exists. These groundrules are as follows:

(1) The design must operate during a continuation of the worst-case conditions as long as a probability exists for the occurrence of such conditions.

(2) For capillary retention and capillary dominated feed, a $\underline{\overline{\phi}}$ value of one-half the actual value will be used.

(3) For hydrostatic refill, a Φ value of twice the actual value will be used.

(4) Minimum liquid-fill levels in the tanks will be assumed prior to final operation of any system.

(5) Rotational attitude control motions, start, and stop are powered for 2 deg of rotational arc. The remaining rotation takes place under a coast condition.

The vehicle acceleration environment influences system design in that it dictates the orientation or location of bulk propellants in the tanks with respect to the tank outlet and generates the hydrostatic pressures against which stabilizing surface-tension forces must be matched. This acceleration environment is characterized not only by magnitude and direction but also by duration and sequence. Often a retention system can survive short-duration high-level accelerations. Table B-1 represents a survey of the acceleration environment that is anticipated on the orbiter for the various vehicle configurations. The minimum and maximum values shown result from particular combinations of vehicle mass and thrust level for the indicated propulsion system. The accelerations due to vehicle rotational motions are the tangential components only. It has been assumed that thruster power is applied through 1 deg to 2 deg of arc for starting and stopping these motions, and under this assumption the tangential components of acceleration are the dominant ones. During the coast period of rotation, the normal or centrifugal component is dominant but is much smaller than the tangential component proceeding or following the motion.

The accelerations shown in Table B-2 are those anticipated at the particular tankage indicated. These values have been calculated from a hypothetical vehicle configuration and tank location. The translational accelerations are not dependent on tank location and are the maximum values taken from Table B-1 regardless of any particular vehicle design. Thus, these accelerations represent the worst combination of both design configurations.

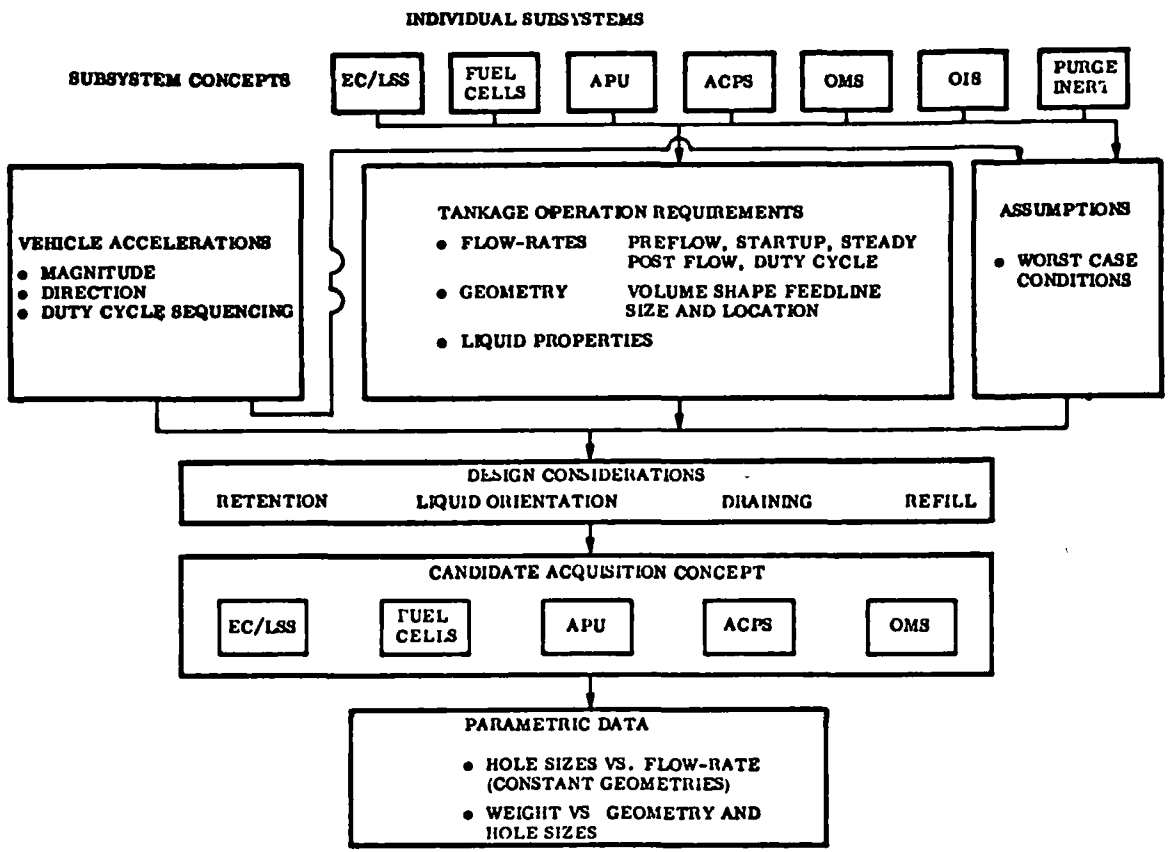


Fig. B-1 Propellant Acquisition System Approach Individual Subsystems

Table B-1

ACCELERATIONS AFFECTING ACQUISITION SYSTEMS

CONTRTR.	SUBSY.	VEHICLE	ACCELERATION / DIRECTION			COMMENTS
			x	y	z	
North American Rockwell	OMS	LCR (Max)	$+7.35 \times 10^{-2}$g			
		HCR (Min)	$+6.20 \times 10^{-2}$g			
	ACPS	LCR (Max)	$\pm 2.24 \times 10^{-2}$g	$\pm 3.98 \times 10^{-2}$g	$\pm 3.98 \times 10^{-2}$g	Translational
		HCR (Min)	$\pm 0.65 \times 10^{-2}$g	$\pm 1.43 \times 10^{-2}$g	$\pm 1.43 \times 10^{-2}$g	Translational
		LCR (Max)	-	$\pm 7.01 \times 10^{-2}$g	$\pm 7.43 \times 10^{-2}$g	Rotational
		HCR (Max)	-	$\pm 6.03 \times 10^{-2}$g	$\pm 6.03 \times 10^{-2}$g	Rotational
McDonnell-Douglas	OMS	LCR (Max)	$+4.71 \times 10^{-2}$g	-	-	
		HCR (Min)	$+2.52 \times 10^{-2}$g	-	-	
	ACPS	LCR (Max)	$+4.63 \times 10^{-2}$g	$\pm 2.98 \times 10^{-2}$g	$\pm 2.12 \times 10^{-2}$g	Translational
		" "	-1.43×10^{-2}g			
		LCR (Min)	$\pm 0.68 \times 10^{-2}$g	$\pm 1.43 \times 10^{-2}$g	$\pm 1.02 \times 10^{-2}$g	
		HCR (Max)	$+2.92 \times 10^{-2}$g	$\pm 4.26 \times 10^{-2}$g	$\pm 4.26 \times 10^{-2}$g	
		" "	-1.43×10^{-2}g			
		HCR (Min)	$\pm 0.68 \times 10^{-2}$g	$\pm 2.08 \times 10^{-2}$g	$\pm 2.08 \times 10^{-2}$g	
		LCR (Max)		$\pm 6.55 \times 10^{-2}$g	$\pm 4.79 \times 10^{-2}$g	Rotational
		HCR (Max)		$\pm 9.85 \times 10^{-2}$g	$\pm 10.3 \times 10^{-2}$g	Rotational

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Table B-2

VEHICLE ACCELERATION LEVELS ON TANKAGE FOR INDIVIDUAL SUBSYSTEMS

Tankage	Direction and Magnitude			Comments
	X	Y	Z	
Translation				
OIS	+ 3 g	----	----	During initial 463 sec of mission only
OMS	+ 6.2×10^{-2} g	----	----	Ascent and Deorbit
ACPS	$\pm 4.6 \times 10^{-2}$ f	$\pm 4.0 \times 10^{-2}$ f	$\pm 4.0 \times 10^{-2}$ g	No Specific Sequence
Rotational				
OMS	$\pm 1.65 \times 10^{-2}$ g	$\pm 4.3 \times 10^{-2}$ g	$\pm 4.3 \times 10^{-2}$ g	No Specific Sequence
ACPS	$\pm 1.65 \times 10^{-2}$ g	$\pm 5.4 \times 10^{-2}$ g	$\pm 5.4 \times 10^{-2}$ g	
APU	$\pm 1.65 \times 10^{-2}$ g	$\pm 6.5 \times 10^{-2}$ g	$\pm 6.5 \times 10^{-2}$ g	
Fuel Cell and EC/LSS	$\pm 1.65 \times 10^{-2}$ g	$\pm 10.8 \times 10^{-2}$ g	$\pm 10.8 \times 10^{-2}$ g	
Reentry	- 0.25 g	----	- 1.07 g	Not applicable to OMS and OIS tankage

Maximum acceleration levels for a hypothetical vehicle and tankage configuration based on a worst case combination of NAR and MDC designs.

The reentry accelerations are based on an initial vector of approximately 1g acting at an angle of 105 deg to the +X axis and finally assuming a 90-deg orientation during the landing phase.

Table B-3 presents data and operational requirements for tankage of each system that will require a propellant acquisition system. The orbit injection system tanks will not require orientation systems, because the mission for these tanks is a single burn following booster separation and a very short coast. At this time, the propellants will be properly oriented. The data in Table B-3 are sufficiently accurate for defining acquisition system concepts applicable to the designs of the Phase B designs.

Not shown in Table B-3 are some additional operational requirements, particularly the individual propellant tanks.

In general, the OMS tanks are the only ones for which propellant withdrawal, engine thrust, and propellant settling are coincident in time. The ACPS tanks, with the requirement for accumulator charging not necessarily coincident with thruster activity, must provide liquid feed under arbitrary conditions of vehicle acceleration and propellant orientation. The same is true for the fuel cell and EC/LSS tanks and to a certain extent the APU tanks. Most of the propellant in the APU tanks is consumed during orbit injection, reentry, and landing periods of high vehicle acceleration when the propellant orientation can be predicted. However, the APU must be restarted on orbit under conditions of arbitrary accleration with unpredictable propellant orientation.

From the standpoint of propellant feed duty cycle and propellant orientation as dictated by the vehicle accelerations, two general categories of capillary retention systems can be defined: (1) those configurations which allow liquid propellant feed independent of the bulk-liquid orientation in the tanks can be called "acquisition" or distributed inlet feed systems. (2) those configurations which provide liquid feed for a limited period of time but which depend ultimately on a particular bulk-liquid orientation

Table B-3

PARTIAL LIST OF REQUIREMENTS INFLUENCING PROPELLANT ACQUISITION SYSTEMS

SUBSYSTEM	PROPELLANT	TANK SHAPE	TANK DIMENSION	FEEDLINE DIAMETER	MAX STEADY FLOW (lb/sec)
OMS	LO_2	Sphere	100 - 120 in.	2.5-3.5	28 - 29
	LH_2	Cylinder-spherical Bulkhead	L 75 - 80 in. D 130 - 150 in.	2.5-3.5	5 - 6
ACPS	LO_2	Sphere	55 - 65 in.	2.5 - 3	10 - 12
	LH_2	Cylinder-spherical	L 130 - 140 in. D 55 - 65 in.	1 - 1.5	2 - 2.5
APU	LO_2	Sphere	24 - 26 in.	0.25-0.3	0.2 - 0.3
	LH_2	Sphere	65 - 70 in.	0.3 - 0.4	0.3 - 0.4
FUEL CELL	LO_2	Sphere	33 - 40 in.	0.25-0.3	$5 \times 10^{-3} - 6 \times 10^{-3}$
	LH_2	Sphere	42 - 50 in.	0.25-0.3	$6 \times 10^{-4} - 7 \times 10^{-4}$
EC / LSS	LO_2	Sphere	13 - 34	0.25-0.3	$9 \times 10^{-5} - 1 \times 10^{-4}$
	LH_2	Sphere	14 - 34	0.25-0.3	$4 \times 10^{-5} - 5 \times 10^{-5}$

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as dictated by vehicle acceleration can be termed "partial retention" or "restart" systems. Generally, the acquisition type of system will have inlets distributed throughout the tank interior near the wall and must maintain capillary-supported stability in the gross dimensions of the propellant tank and must remain filled with liquid at all times.

The restart type of system, on the other hand, retains only enough liquid to support tank feed requirements until vehicle accelerations can promote a predictable propellant orientation. This type of system generally is partially emptied and is filled by the vehicle acceleration levels that orient the propellant, or the system has sufficient volumetric capacity to support a limited number of restarts with liquid refill. The orbiter vehicle tankage can be placed in either of these categories as is shown in Table B-4.

Table B-4

ACQUISITION AND RESTART CATEGORIES OF VEHICLE TANKAGE

	Class	
Tankage	Acquisition	Restart
OMS	x	x
ACPS	x	
APU	x	x
Fuel Cell	x	
EC/LSS	x	

It is to be noted that the acquisition system, because of a lack of restriction on propellant orientation, is applicable to all classes of tankage on the orbiter while only the operational requirements of the OMS and APU tankage permit the use of a restart system.

Surface Tension Screen Design

Analyses were conducted regarding the required capillary stability and available screens. The results are presented in Figure B-2. The range of subsystem requirements is indicated. As may be seen, the required screen sizes are smaller than desirable from the standpoint of reusability and pressure drop. The use of multiple screens, as presented in Figure B-3, is capable of providing the required capaillary stability. The procedure for manufacturing these inlets is shown in Figure B-4.

Surface Tension Device Concepts

The possible methods of employment of acquisition devices in an Orbit Maneuvering Propulsion Supply integrated with the Attitude Control Propulsion Supply and possibly other subsystems are presented in Figure B-5. (1) The screen liner concept presents a number of difficulties relative to the employment of multiple screens. (2) The compartmented concept is better suited, but is very mission-profile sensitive. (3) The manifold pickup concept allows the use of multiple screens, but the hydrostatic head during ascent requires the use of very small screens. (4) The composite concept presented provides what appears to be the best approach to utilization of the multiple screens. The compartment is sized for all attitude control propulsion requirements, orbit maneuvering propulsion start, and other subsystem requirements between OMPS engine operations. The compartment is refilled during orbit maneuvering engine operation through the communication ports. Liquid can only flow from the tank into the compartment. The typical operating modes are illustrated in Figure B-6.

Investigation of Design Problems

It has been recognized that if a surface-tension screen is not covered by liquid and is "stressed" by virtue of flow from the device, some gas will enter the device. In a multiple screen device, it is possible to estimate

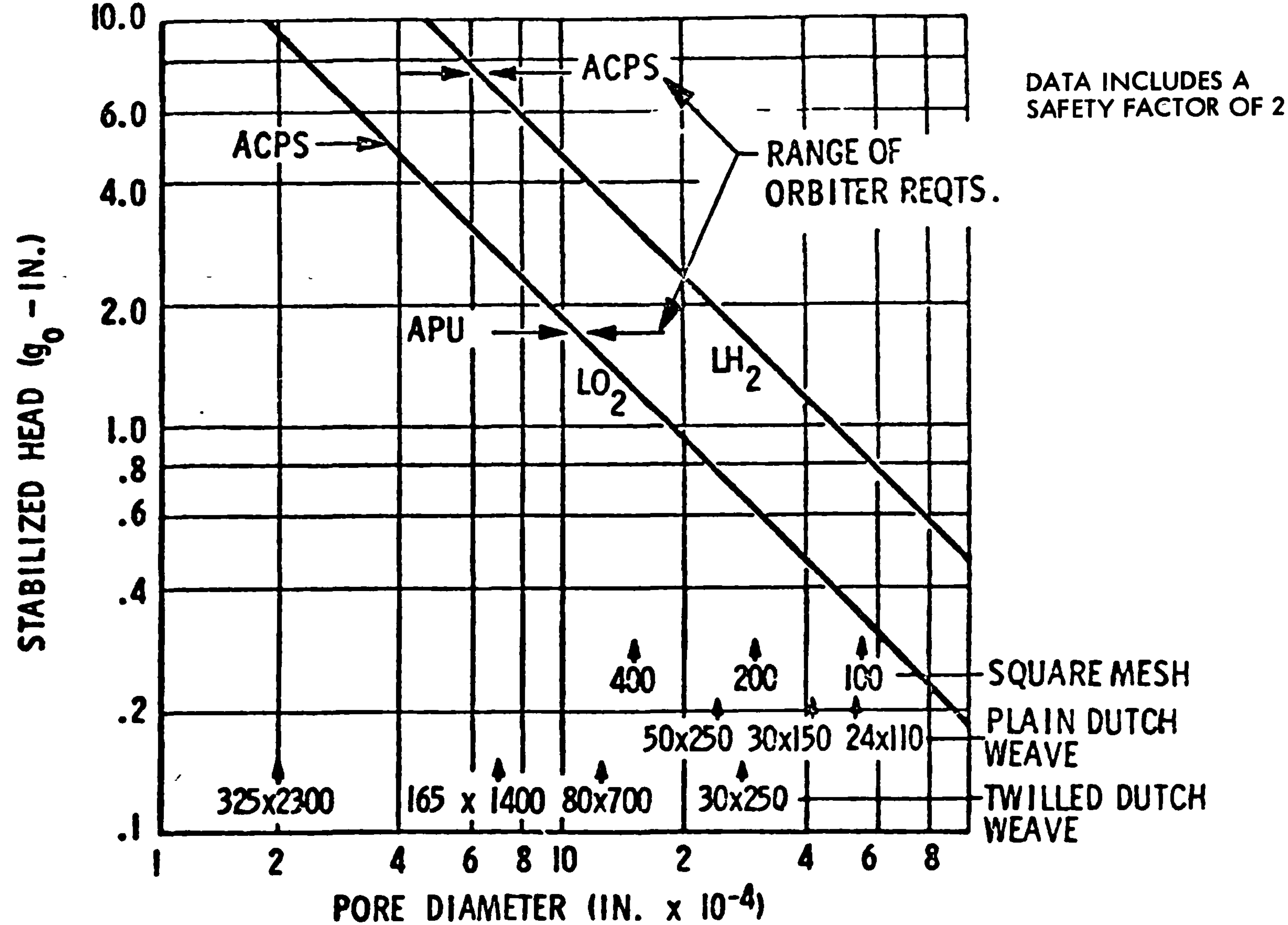

Fig. B-2 Capillary Stability Map (For Shuttle Cryogenic Subsystem Requirements)

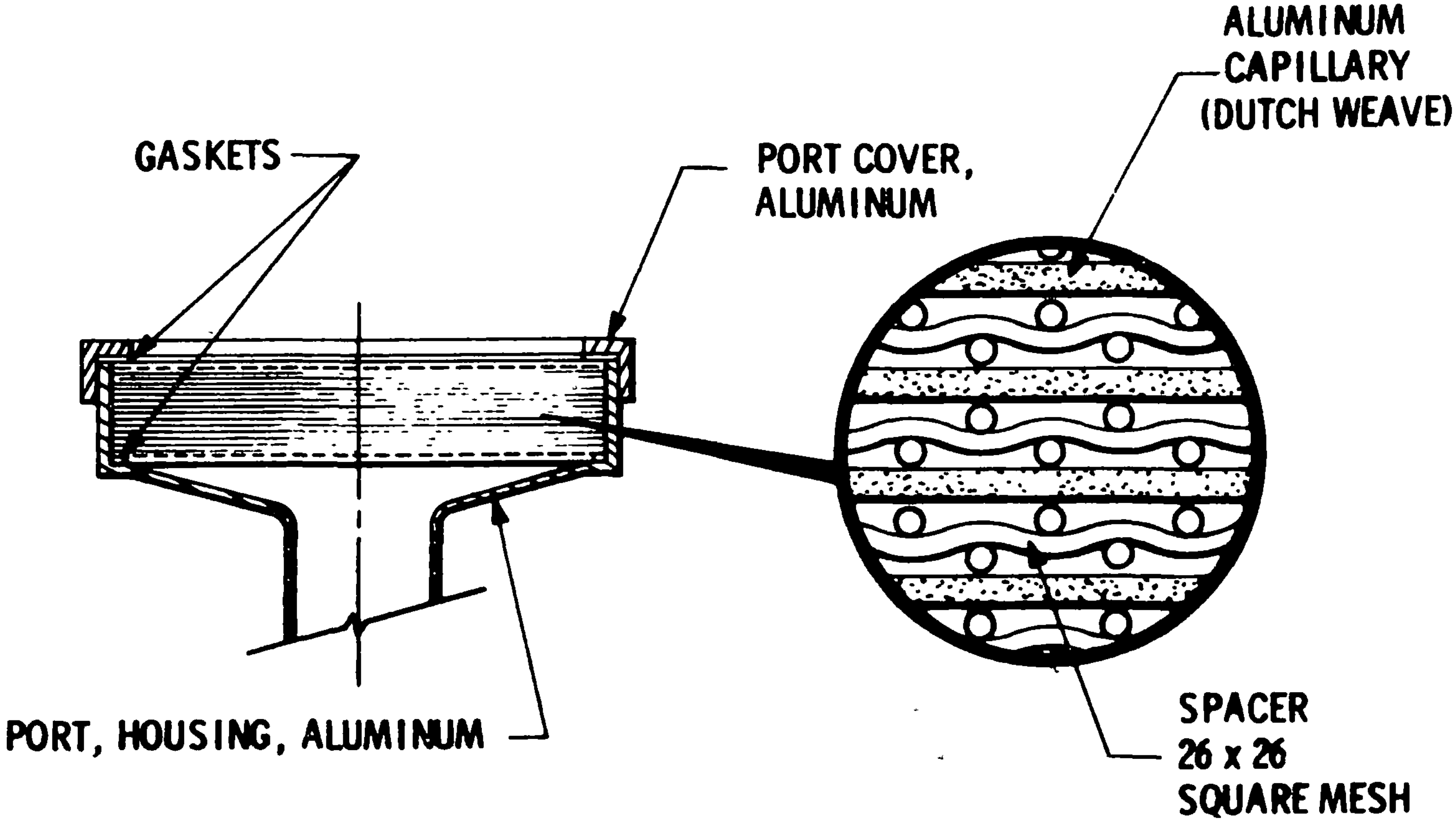

Fig. B-3 Inlet Port Using LMSC Multiple-Screen Concept

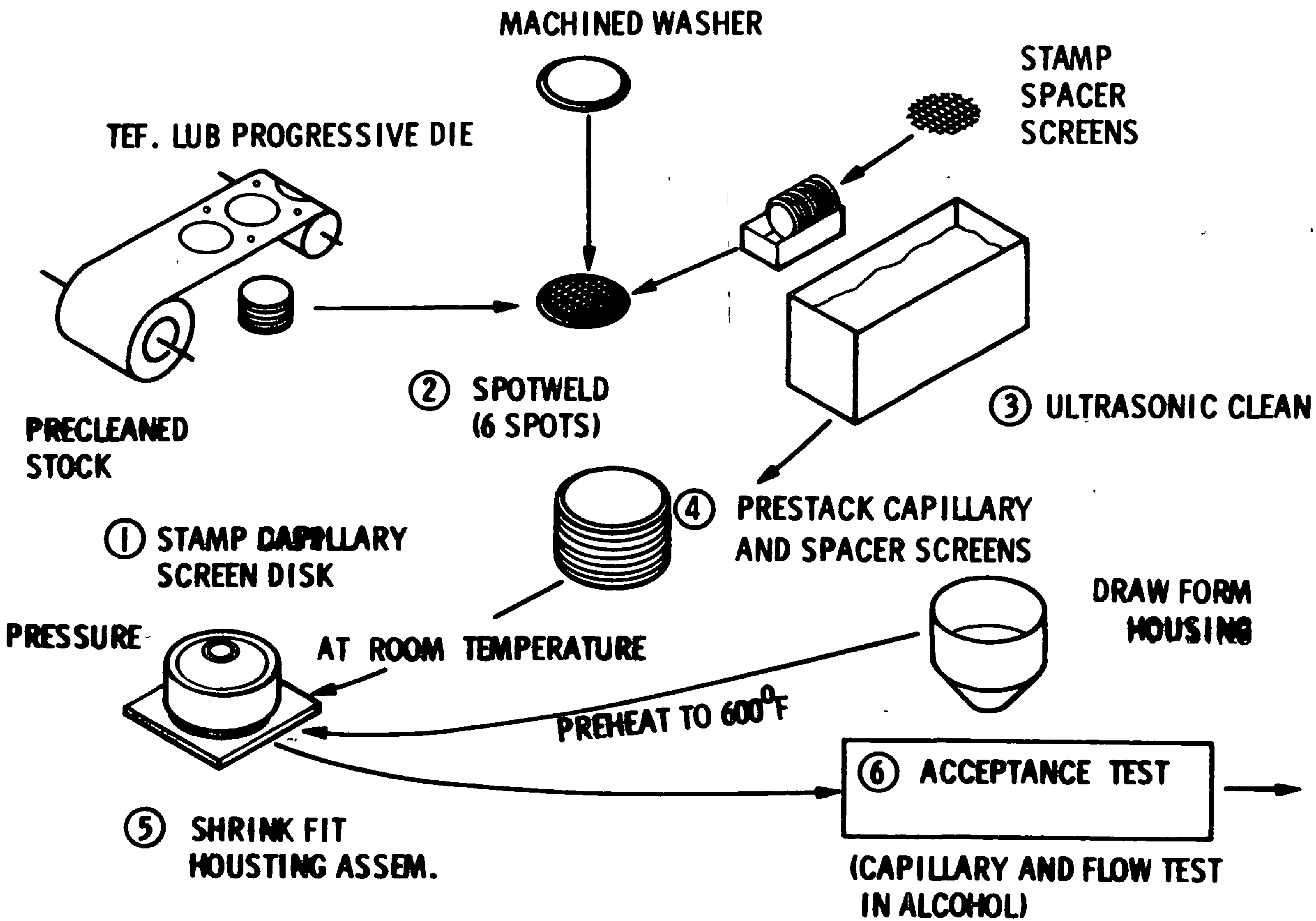

Fig. B-4 Manufacture of Inlet Ports

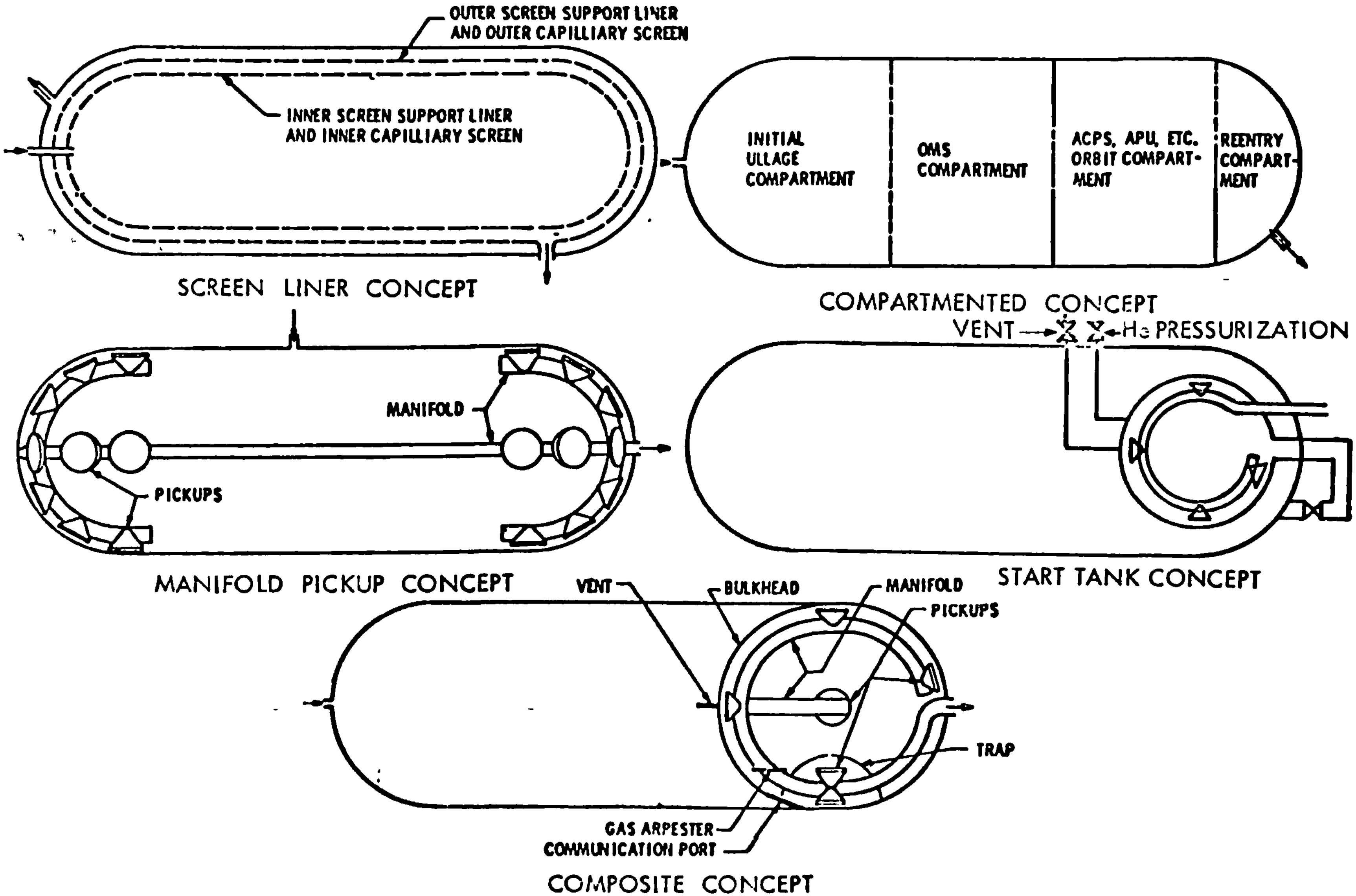

Fig. B-5 Candidate Design Concepts

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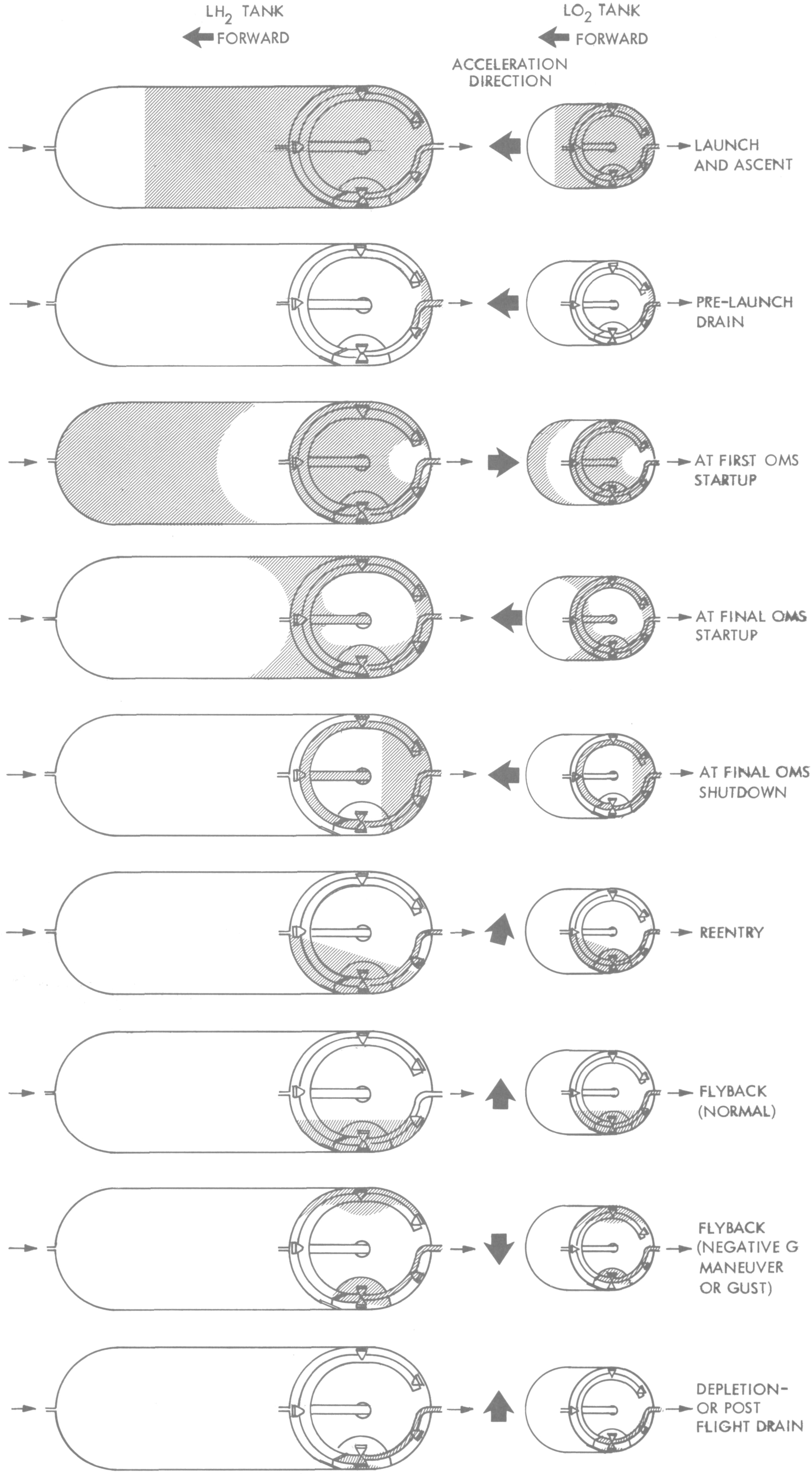

Fig. B-6 Typical Operating Modes

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the amount of gas which could be trapped in the inlet ports (resulting from the liquid "level" which would be achieved in the multiple screens).

The following assumptions were used in the analyses:

(1) $g = 0.075\ g_o$

(2) Flowrates

LH_2 - 2.5 lbm/sec

LO_2 - 12.5 lbm/sec

(3) One inlet port is in liquid

(4) Compartment is 1/3 full of propellant

(5) Feedline is sized for negligible ΔP effect

(6) Screen mesh is initially filled with liquid

(7) Tank pressures

Liquid Hydrogen		
	Vapor Pressure	16 psia
	Total Pressure	24 psia
Liquid Oxygen		
	Vapor Pressure	16 psia
	Total Pressure	58 psia

The results of analyses are presented in Tables B-5 and B-6, which provide a number of parameters. The parameters can be used to illustrate various sensitivities and effects.

Through the use of crossplots, the maximum gas volume which might be ingested through an uncovered device has been determined and is presented in Fig. B-7. The parameter held constant was pressure drop. The total gas possibly ingested is the sum of the GHe and GH_2 or GO_2, respectively. Naturally, all of the gas is not ingested immediately. It may be ingested over a period of time as small bubbles.

Table B-5

LIQUID HYDROGEN INLET PORT PARAMETERS

Mesh Size	Diameter (In.)	No. of Screens	Area Inlet ($In.^2$)	Weight (Lb) Stainless Steel	Weight (Lb) Aluminum	Δp (psia)	Vol He ($In.^3$)	Vol GH_2 ($In.^3$)
24X110	12	39	113	28.2	9.5	0.156	65.7	131
	14	10	154	9.7	3.3	0.04	21	42
	15	8	177	8.7	2.9	0.032	18.9	39.8
30X150	12	14	113	7.8	2.66	0.072	15.2	30.4
	13	8	133	5.15	1.74	0.041	9.6	19.2
	14	7	154	5.17	1.75	0.036	9.5	19
50X250	11	9	95	2.86	0.97	0.078	4.3	8.5
	12	5	113	1.8	0.61	0.043	2.6	5.1
	13	4	133	1.63	0.55	0.031	2.2	9.5
200X1400	9.0	3	64	0.36	-	0.162	0.29	0.58
	9.5	2	71	0.24	-	0.108	0.16	0.33
	10.0	1	78.5	0.87	-	0.05	-	-

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Table B-6

LIQUID OXYGEN INLET PORT PARAMETERS

Mesh Size	Diameter (In.)	No. of Screens	Area Inlet ($In.^2$)	Weight (Lb) Stainless Steel	Weight (Lb) Aluminum	$\Delta \rho$ (psia)	Vol He ($In.^3$)	Vol GH_2 ($In.^3$)
24X110	9	14	64	5.6	1.9	0.4	27.6	10.5
	10	10	79	4.8	1.6	0.29	23	8.8
	11	8	95	4.6	1.56	0.23	21.7	8.3
	12	7	113	4.7	1.61	0.20	22.1	8.4
30X150	8	21	50	5.3	1.8	0.776	22.6	8.6
	9	9	64	2.8	0.94	0.333	11.4	4.3
	10	7	79	2.65	0.895	0.26	10.6	4.0
	11	6	95	2.7	0.91	0.22	10.7	4.1
50X250	7	74	39	10.2	3.4	4.6	34.4	13.1
	8	6	50	0.98	0.33	0.37	3.1	1.2
	9	4	64	0.78	0.27	0.25	2.3	0.9
200X1400	6.25	5	31	0.316	-	1.94	0.62	0.23
	6.50	2	33	0.13	-	0.78	0.17	0.06
	7.0	1	38.5	0.04	-	0.39	-	-

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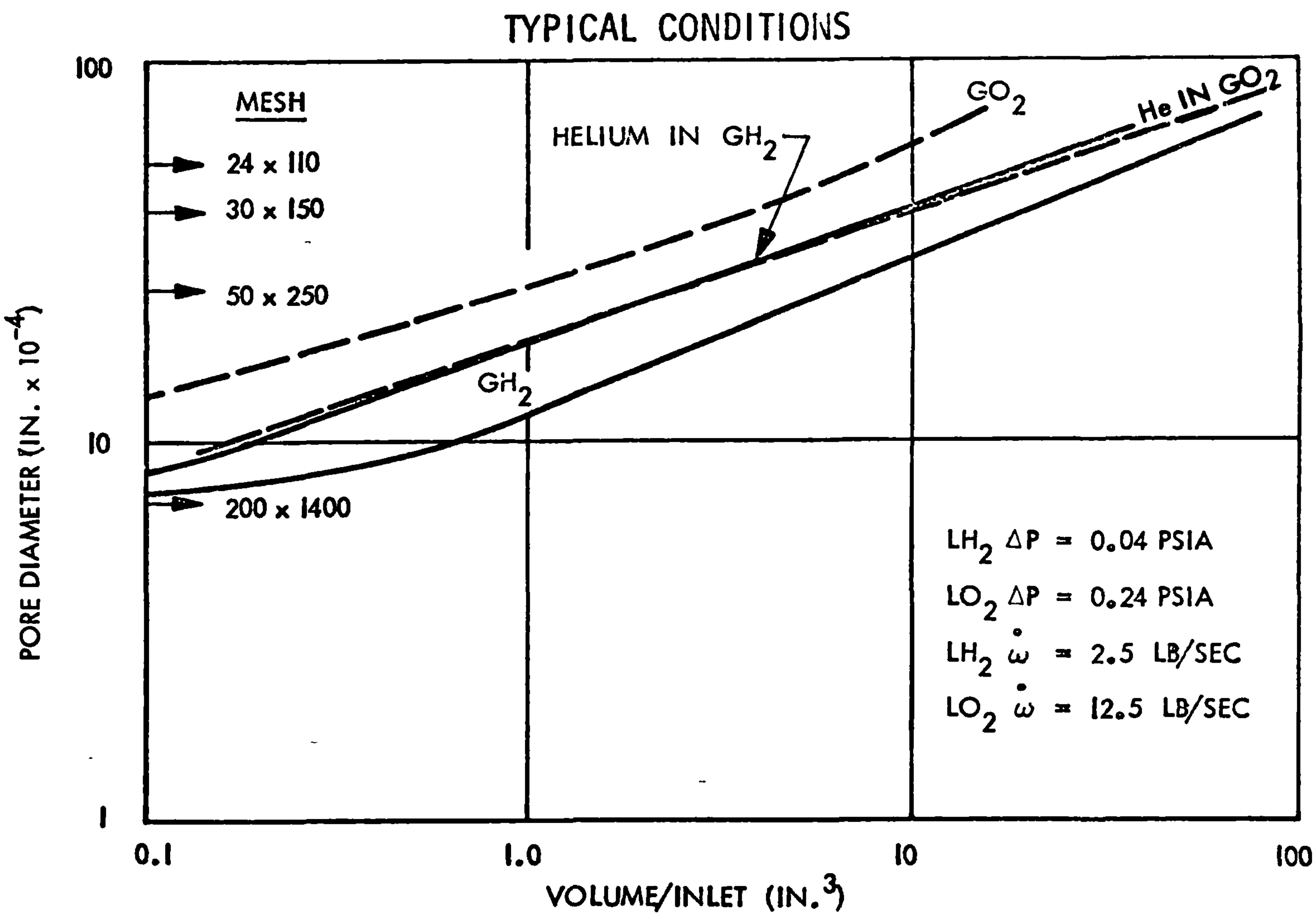

Fig. B-7 Maximum Gas in Multiple Screen Devices

As an example, if the screen mesh were 50 x 250, the total possible gas ingestion could be 5 to 10 cubic inches for a "stressed" uncovered inlet.

The pressure drops in the gallery devices from the engine start transient is a major factor in the sizing of the lines of the gallery. The models examined are presented in Figure B-8. Flow from point 1 provides the maximum pressure drop. If the screens at upstream points are uncovered, then the screens must be capable of resisting the pressure drop without significant gas pull-through. The pressure drop as related to gallery line diameter is presented in Figure B-9 for an RL-10 start transient.

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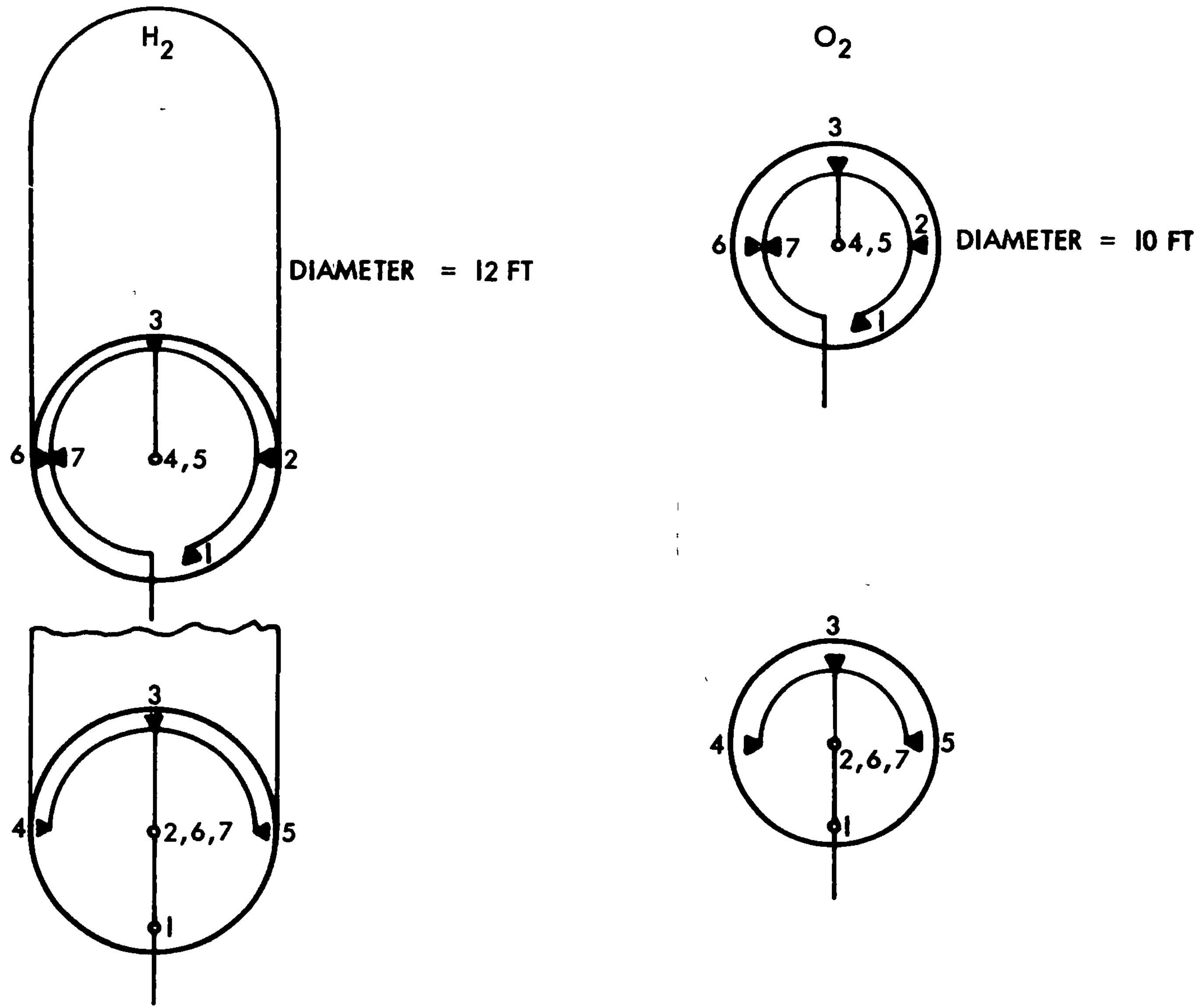

Fig. B-8 Propellant Acquisition Device Configuration

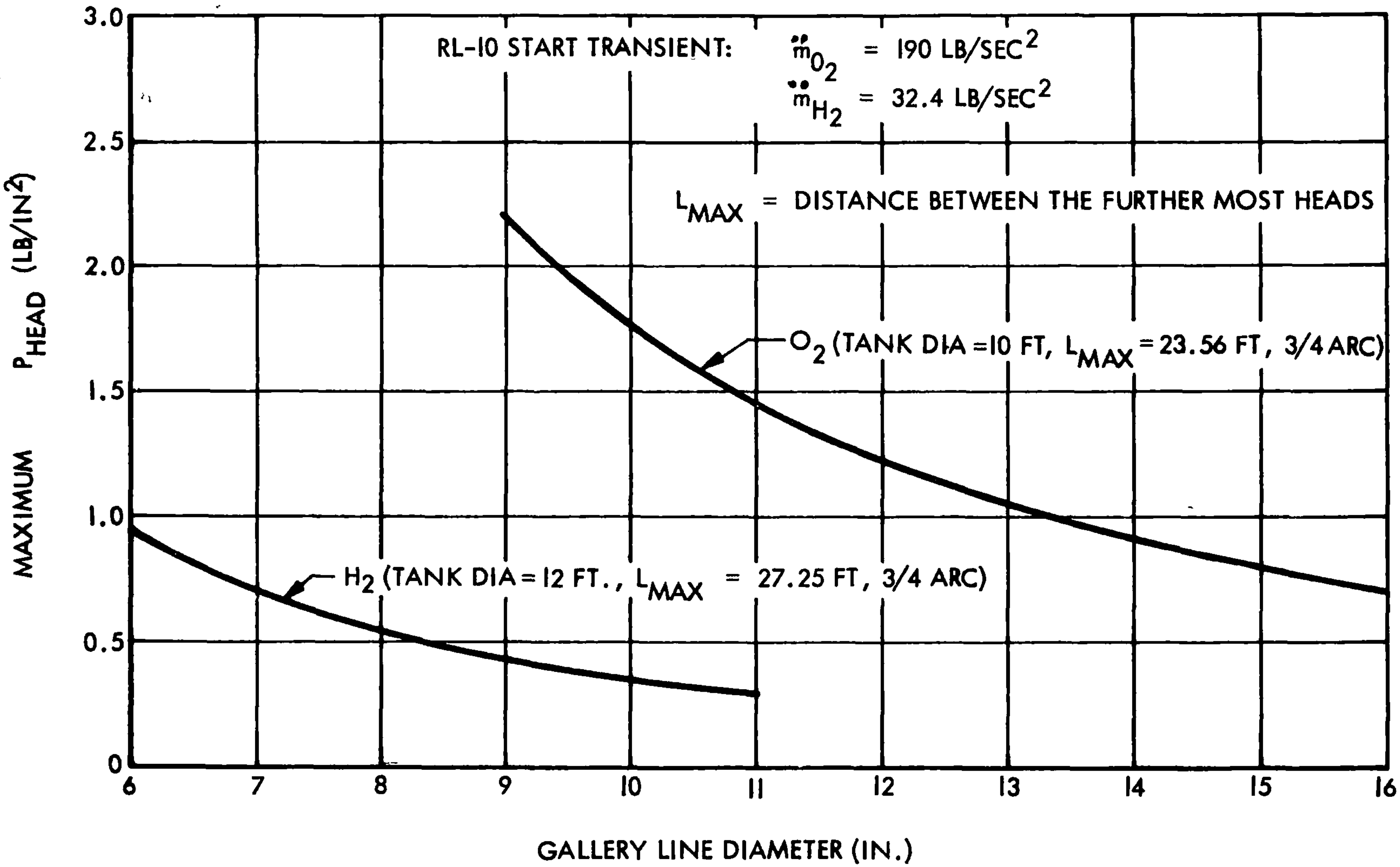

Fig. B-9 Required Heat Differential Capability Vs Gallery Line Diameter

Appendix C

THERMAL PROTECTION AND THERMODYNAMICS

C.1 THERMAL PROTECTION

C.1.1 Multilayer Insulation

Extensive parametric studies were performed for multilayer insulation, and the resulting data are reported in the Task Reports.

The method used to generate these data included the installation degradation and test data. The principal approach was taken from "Investigations Regarding Development of High Performance Insulation Systems", NAS 8-20758, Final Report, Lockheed Missiles and Space Company. Convair Division of General Dynamics was contacted to obtain additional data regarding "Superfloc" insulation.

One of the important factors in the insulation heat input and weight considerations is consideration of the optimum layer density. Based upon available information, LMSC has produced the curves presented in Figure C-1. Based upon these data, layer densities were selected as follows:

- DAM and DGM/Silk Net - 50 or 60 layers/inch
- NRC-2 - 40 layers/inch
- Superfloc - 30 layers/inch

C.1.2 Foam Insulation

Parametric foam insulation data were produced and are presented in the Task Reports.

Thermal conductivity data for polyurethane foam are shown in Figure C-2. A linear relationship, as shown in the figure, was assumed for calculation of heat rates during groundhold. The data of References C-1, C-2 and C-3 are considered more appropriate than the data of Reference 4 because they are characteristic of an aged foam that is primarily air filled. The foam will reach this condition during repeated use.

Figure C-3 shows heat flux as a function of insulation thickness with insulation outer temperature as a parameter. The insulation inner surface temperature at the tank wall was assumed to be 37°R. Figure C-4 shows heat flux as a function of insulation outer surface temperature with insulation thickness as a parameter. Similar curves are shown for the LO_2 ascent tanks in Figures C-5 and C-6. The insulation outer surface temperature will depend on the purge conditions. For example, assuming a 530°R nitrogen environment with a heat transfer coefficient of 1.0 Btu/ft^{2}hr °R and a radiation interchange factor of 0.1 between the tank and surrounding structure, the resulting insulation outer surface temperature and corresponding insulation heat flux are as shown in Figure C-7.

C.1.3 Thermal Gas Barrier

Internal gas barrier parametric data were produced and are presented in the Task Reports. This type of insulation assumed a capillary system which produces a gas layer under high heating rates.

C.1.4 Fiberglass Batting

Purged fiberglass batting was considered as a potential ground-hold insulation. The parametric data are presented in the Task Reports.

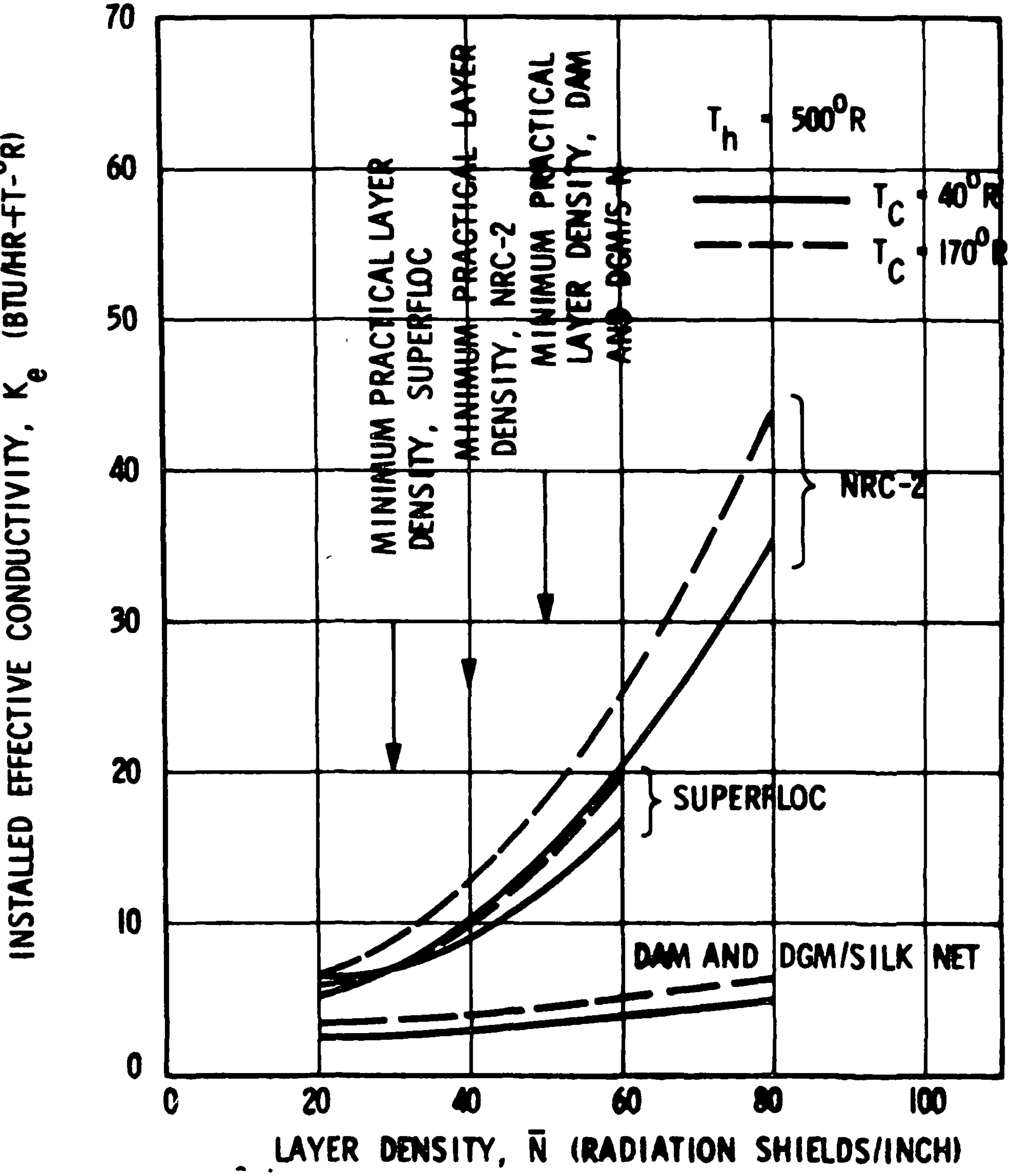

Fig. C-1 Multilayer Insulation Effective Conductivity Versus Layer Density Installation, Degrading Included

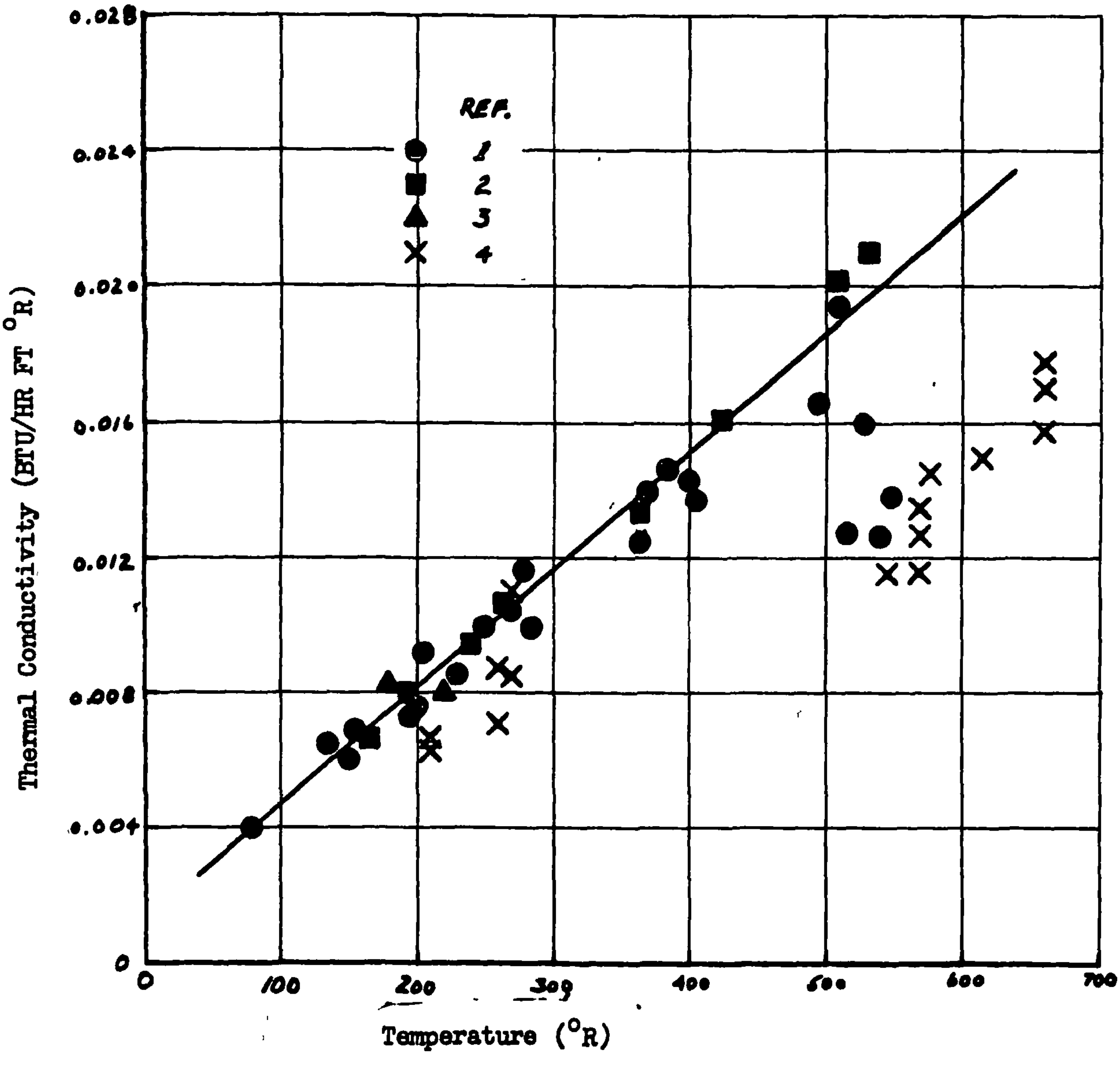

Fig. C-2 Thermal Conductivity of Polyurethane Foam (ρ = 2 lb/ft^3)

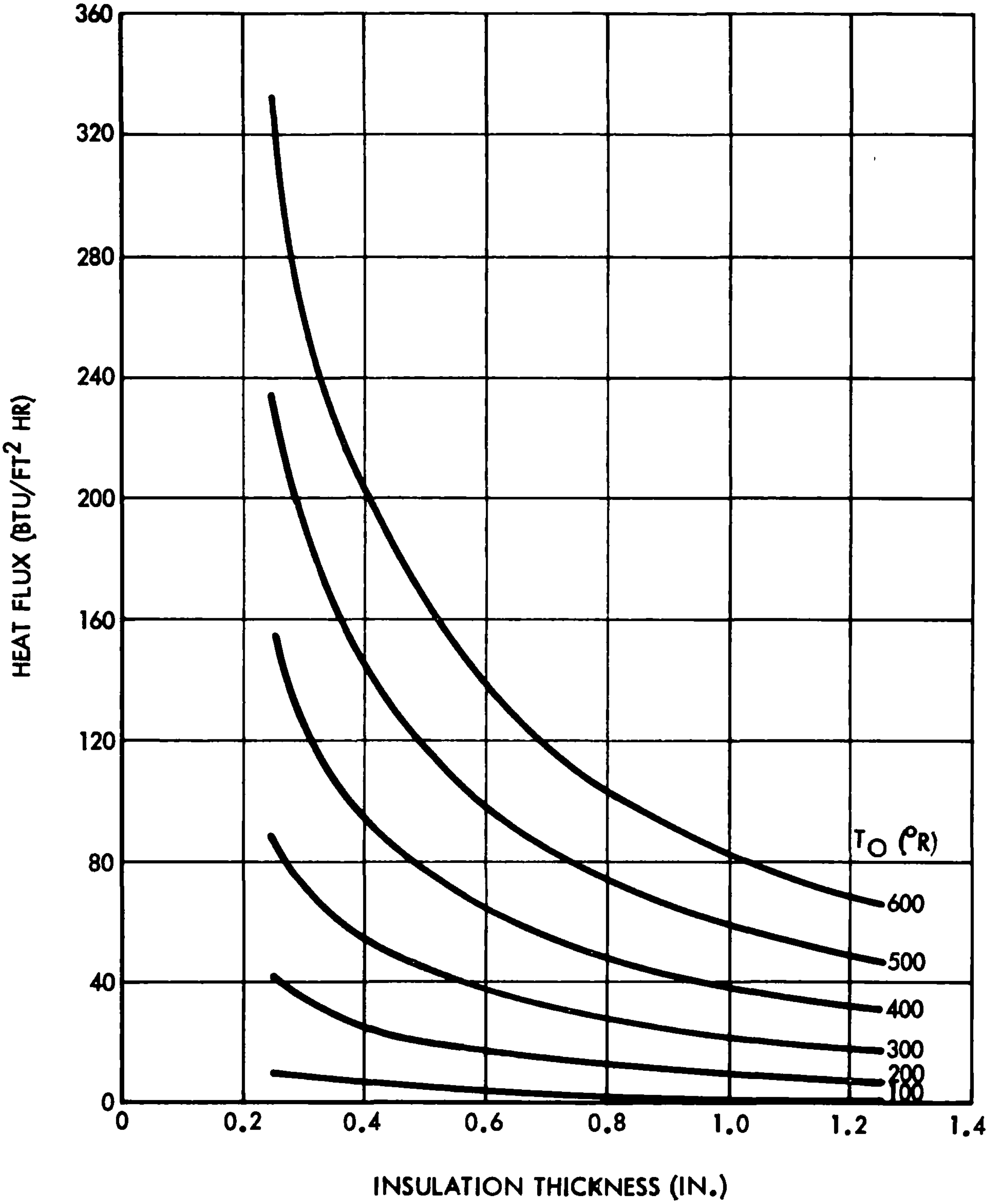

Fig. C-3 LH_2 Tank Heat Flux Versus Polyurethane Foam Insulation Thickness (T_I = 37°R)

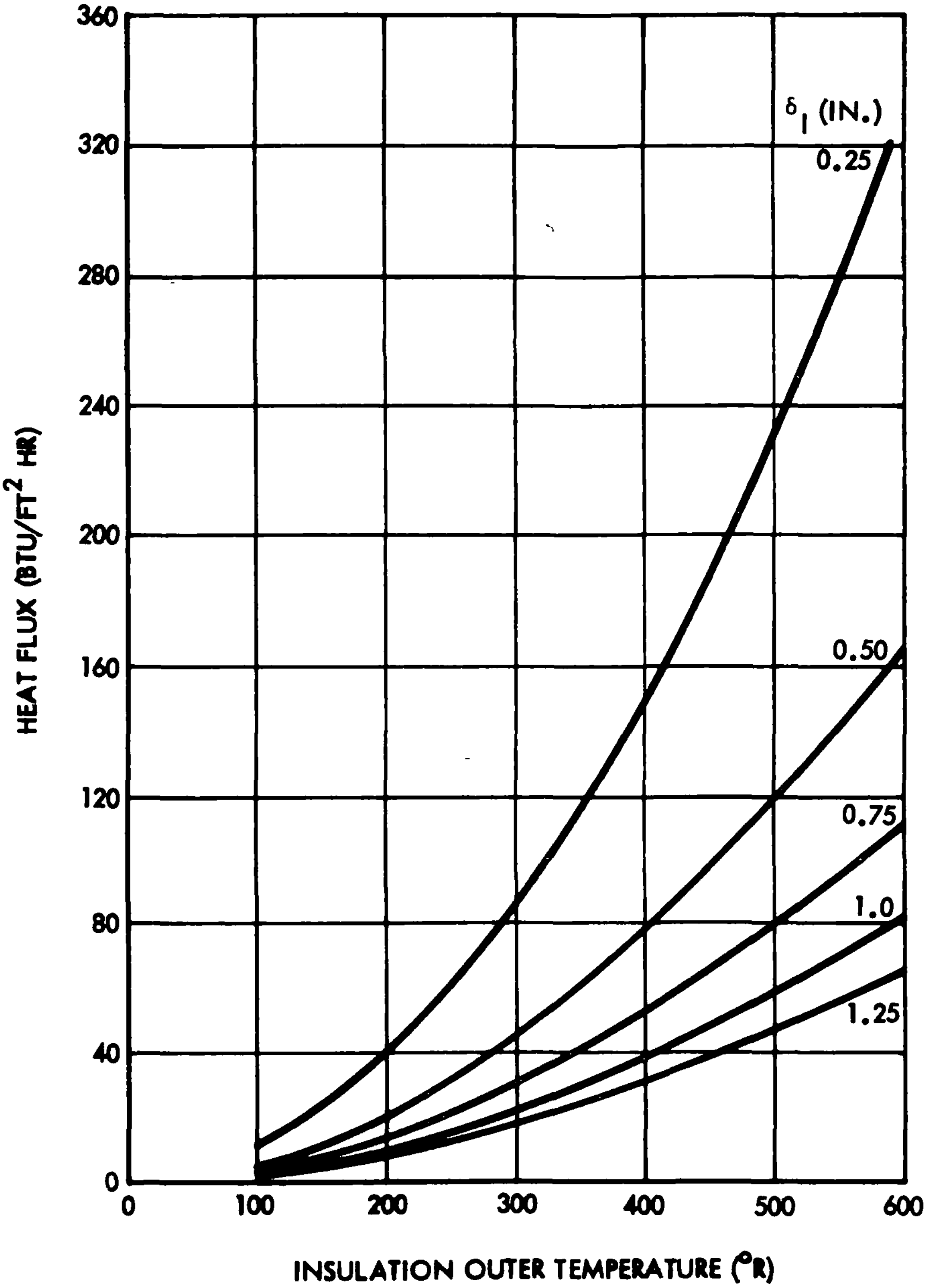

Fig. C-4 LH_2 Tank Heat Flux Versus Polyurethane Foam Outer Surface Temperature (T_I = 37°R)

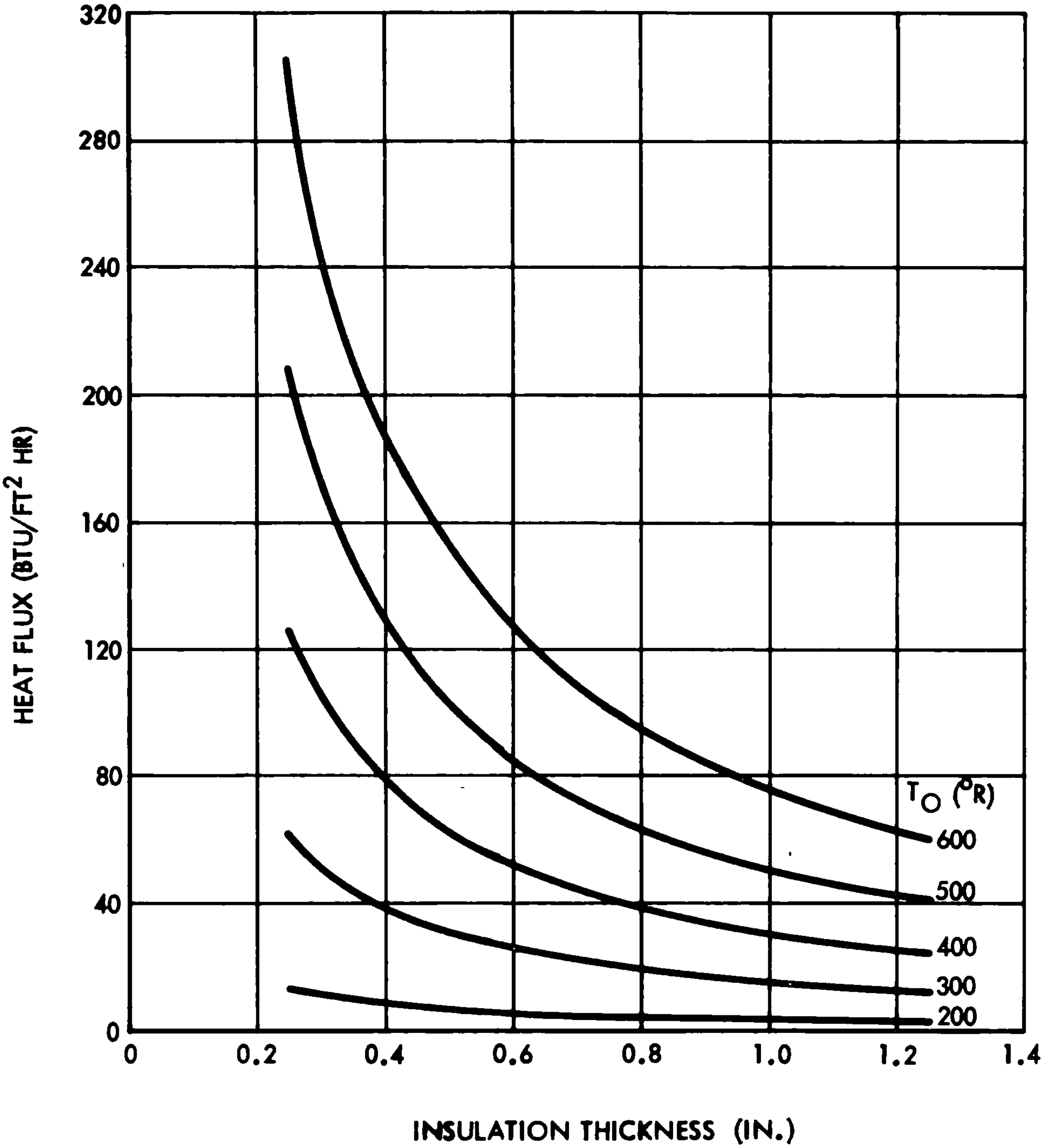

Fig. C-5 LO_2 Tank Heat Flux Versus Polyurethane Foam Insulation Thickness (T_I = 163°R)

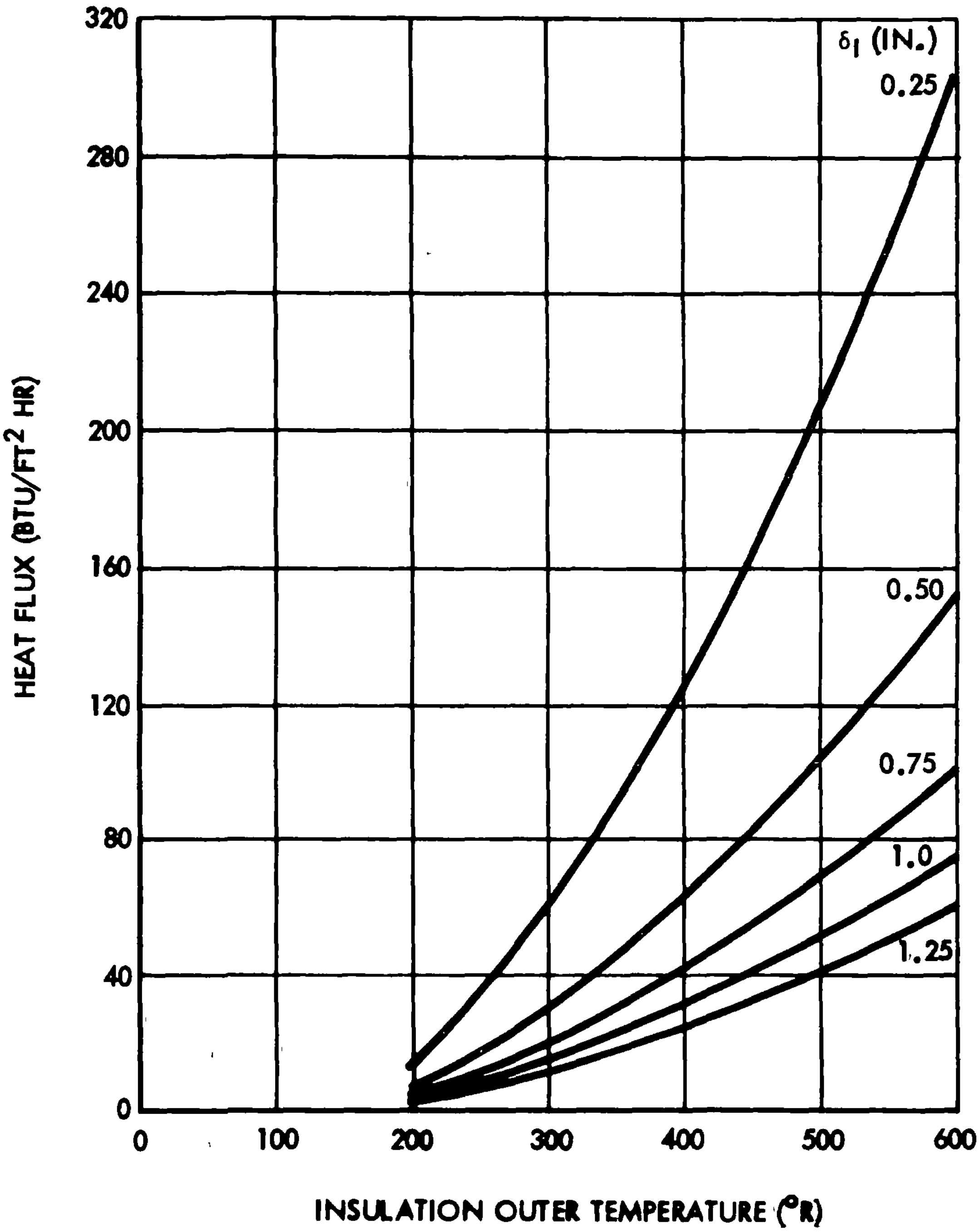

Fig. C-6 LO_2 Tank Heat Flux Versus Polyurethane Foam Outer Surface Temperature (T_I = 163°R)

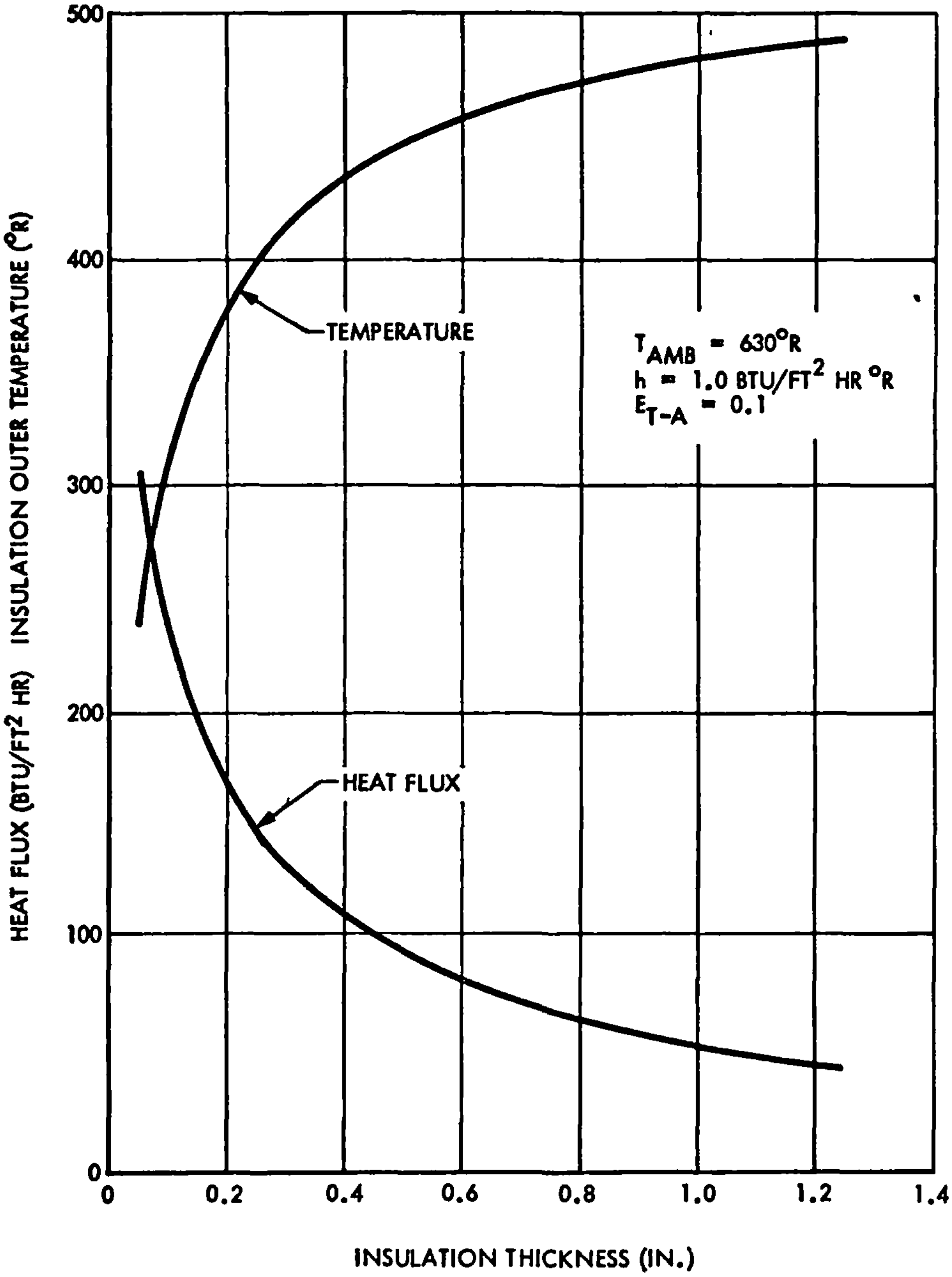

Fig. C-7 LH_2 Tank Heat Flux & Insulation Outer Temperature Versus Polyurethane Foam Insulation Thickness (T_I = 37°R)

Purged fiberglass batting was considered as a potential ground-hold insulation. The parametric data are presented in the Task Reports

C.1.5 Tank Support Heat Leaks

The tank support heat leak data have been obtained from "Cryogenic Tank Support Evaluation", NAS 3-7979, NASA CR 72538, and NASA CR 72545, Lockheed Missiles and Space Company. These data are for optimum insulated struts in vacuum. The data were based upon actual test information. Fiberglass tank support for hydrogen are presented in Figures C-8 and C-9. Similar data for oxygen are presented in Figures C-10 and C-11. Titanium strut data have also been correlated and are presented in Figures C-12 through C-15.

C.2 THERMODYNAMIC ANALYSES

The most important activities in the thermodynamic analyses related to the pressurization studies. These activities are reported in detail.

C.2.1 Orbit Maneuvering Propellant Supply Pressurization Analyses

A portion of Orbit Maneuvering Propellant Supply Pressurization analyses are presented in this section. Additional data are provided in the Task Reports.

The pressurization system analyses were performed with the Thermodynamics Optimization Program (TOP). In the present studies, the TOP program was used to provide a parametric analysis rather than an optimization analysis, since an integrated system optimization will be performed under the study contract. The parametric variations in the present study include the following variables:

- Pressurant inlet temperature
- Expulsion pressure
- Vent pressure
- Insulation thickness
- Tank geometry
- Duty cycle

During prepressurization, mass and energy balances are performed on the ullage vapor, or vapors in the case of helium pressurization. Heat transfer to the ullage wall and liquid propellant is neglected as well as condensation or evaporation at the walls or liquid-vapor interface. During the expulsion, the same type of analysis is performed with the addition of heat transfer between the ullage vapor/vapors and the tank wall exposed by the expulsion. After an expulsion, the tank contents are assumed mixed to achieve thermal equilibrium. Between firings, heat entering the tank is either stored or converted to boiloff, depending on the vent pressure. During this time, the tank contents are maintained in a mixed condition. An initial propellant condition of saturation at 17-psia pressure was assumed for both the oxygen and hydrogen.

The heat rates into the tanks were determined from heat rate curves for double aluminized Mylar 1 silk net with degradation effects included. These curves were constructed as part of the study contract parametric data. An outer boundary temperature of $500^{\circ}R$ was assumed for both oxygen and hydrogen tank insulations. In addition to the insulation heat leak, a penetration heat leak equal to 25 percent of the heat leak through 0.75 inch of insulation was included. The penetration heat leak accounts for heat conducted into the tank through tank supports and plumbing lines.

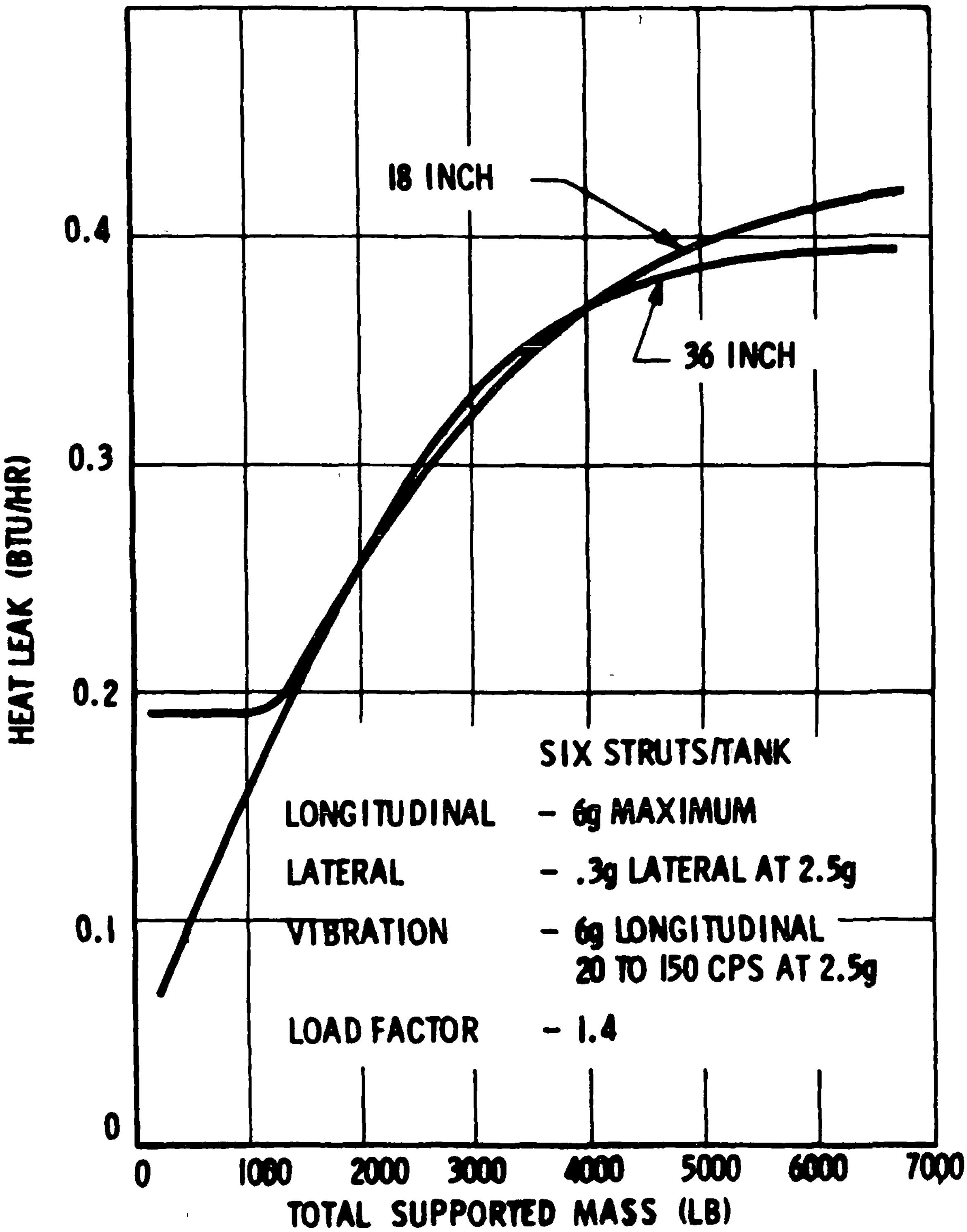

Fig. C-8 Fiberglass Supports - Liquid Hydrogen
(Outer Boundary Layer - 400°F)

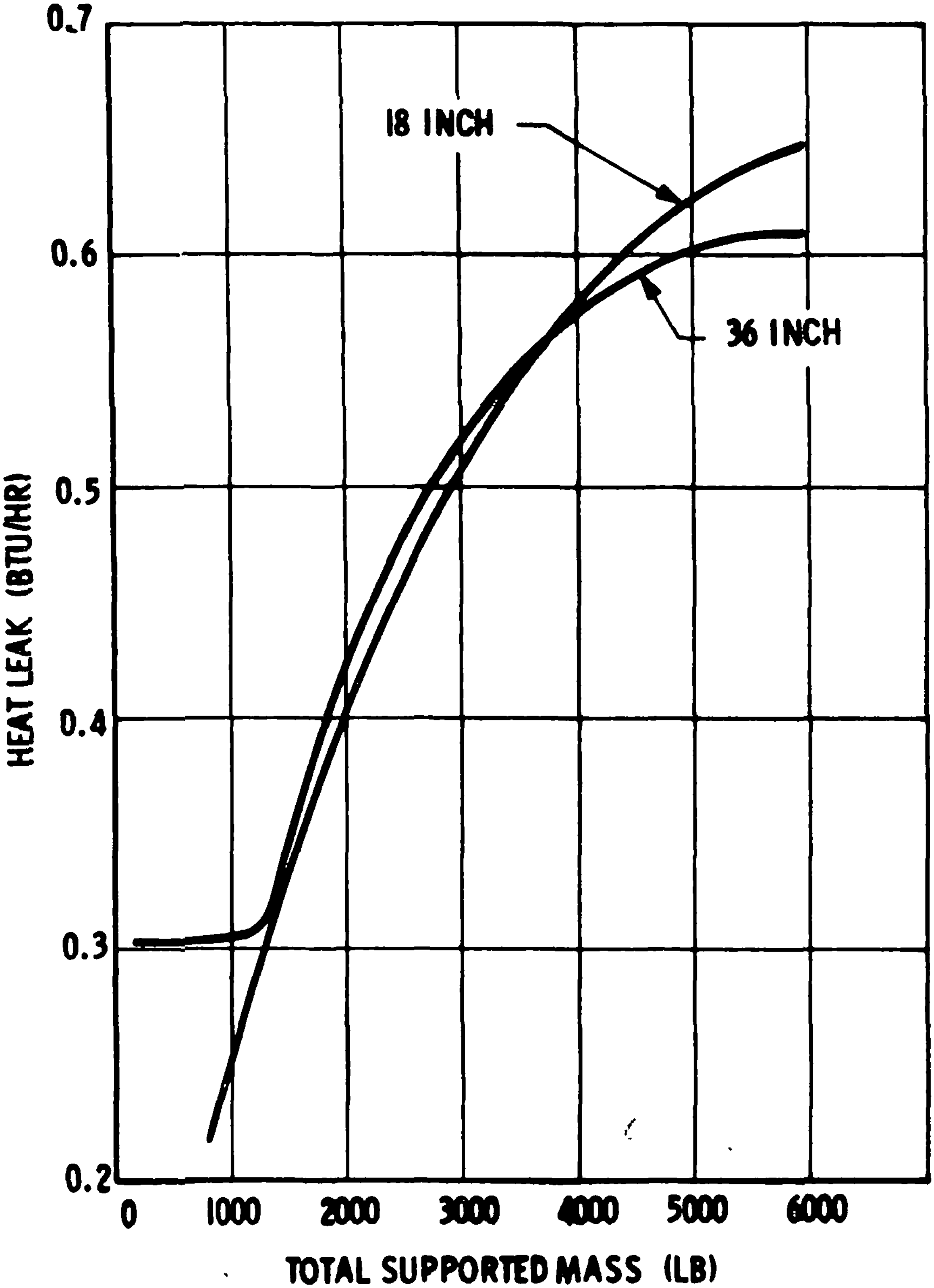

Fig. C-9 Fiberglass Supports - Liquid Hydrogen
(Outer Boundary Layer - 520°R)

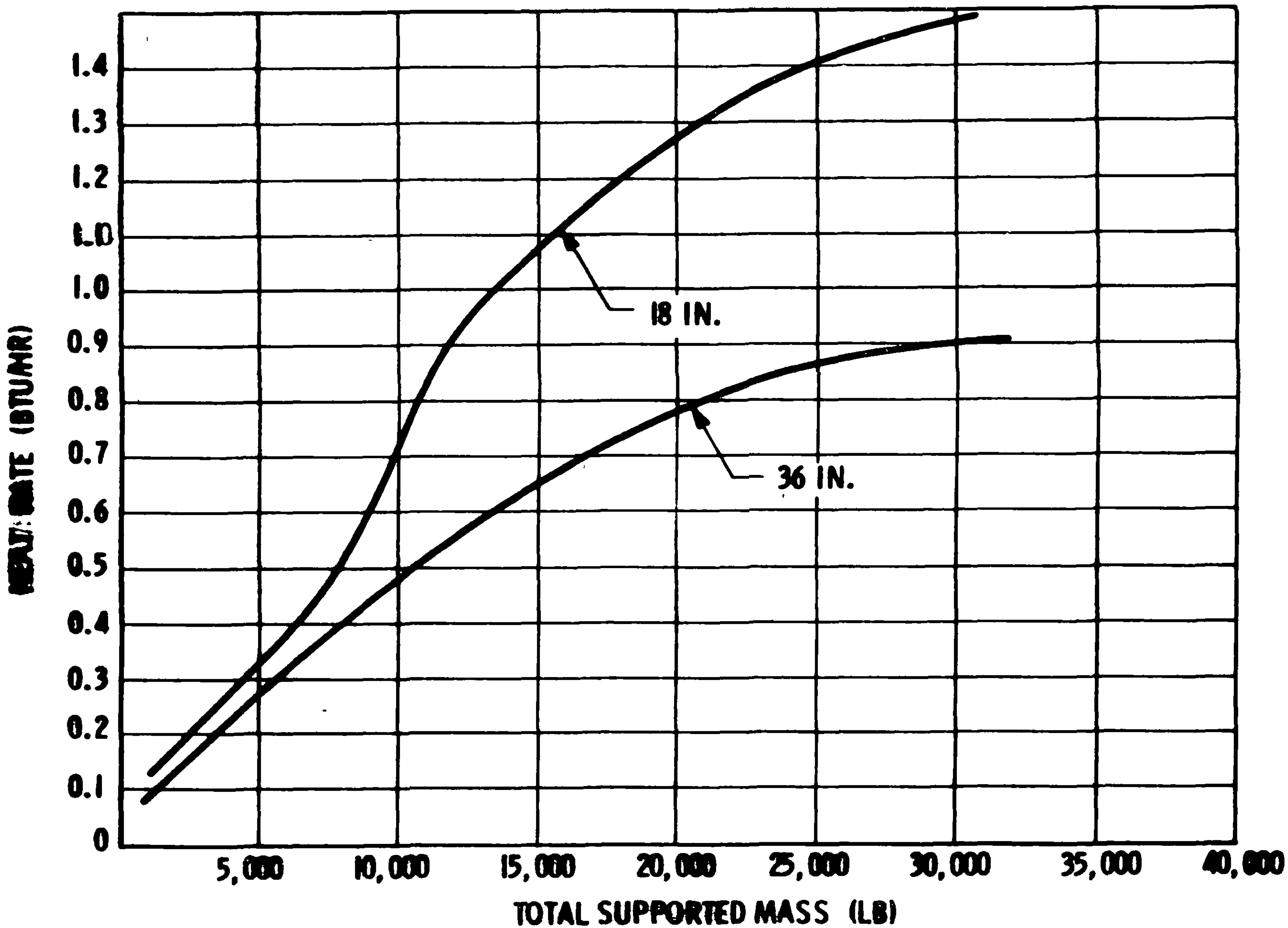

Fig. C-10 Fiberglass Supports - Liquid Oxygen (Outer Boundary Layer - 400°R)

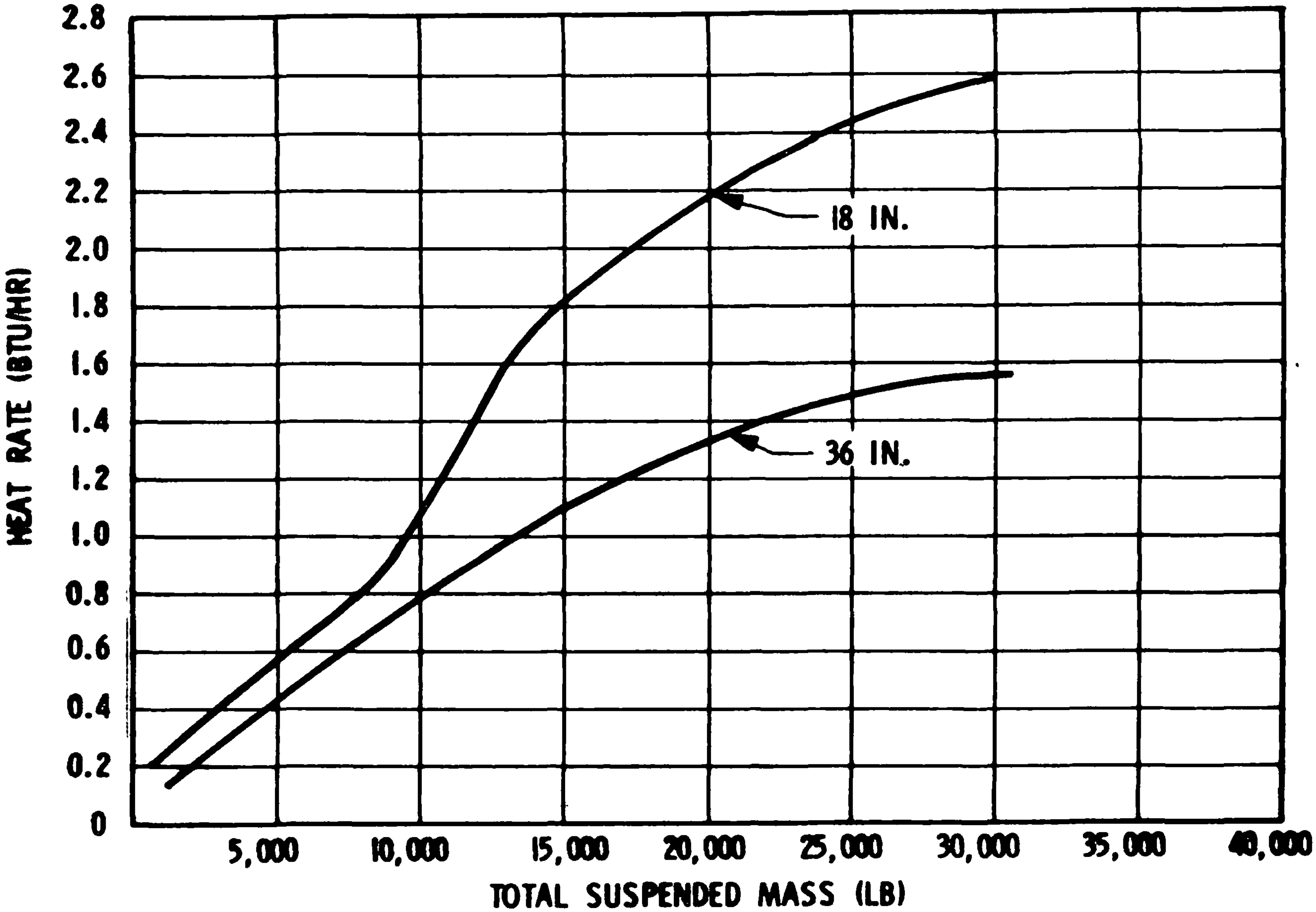

Fig. C-11 Fiberglass Supports - Liquid Oxygen (Outer Boundary Layer - 520°F)

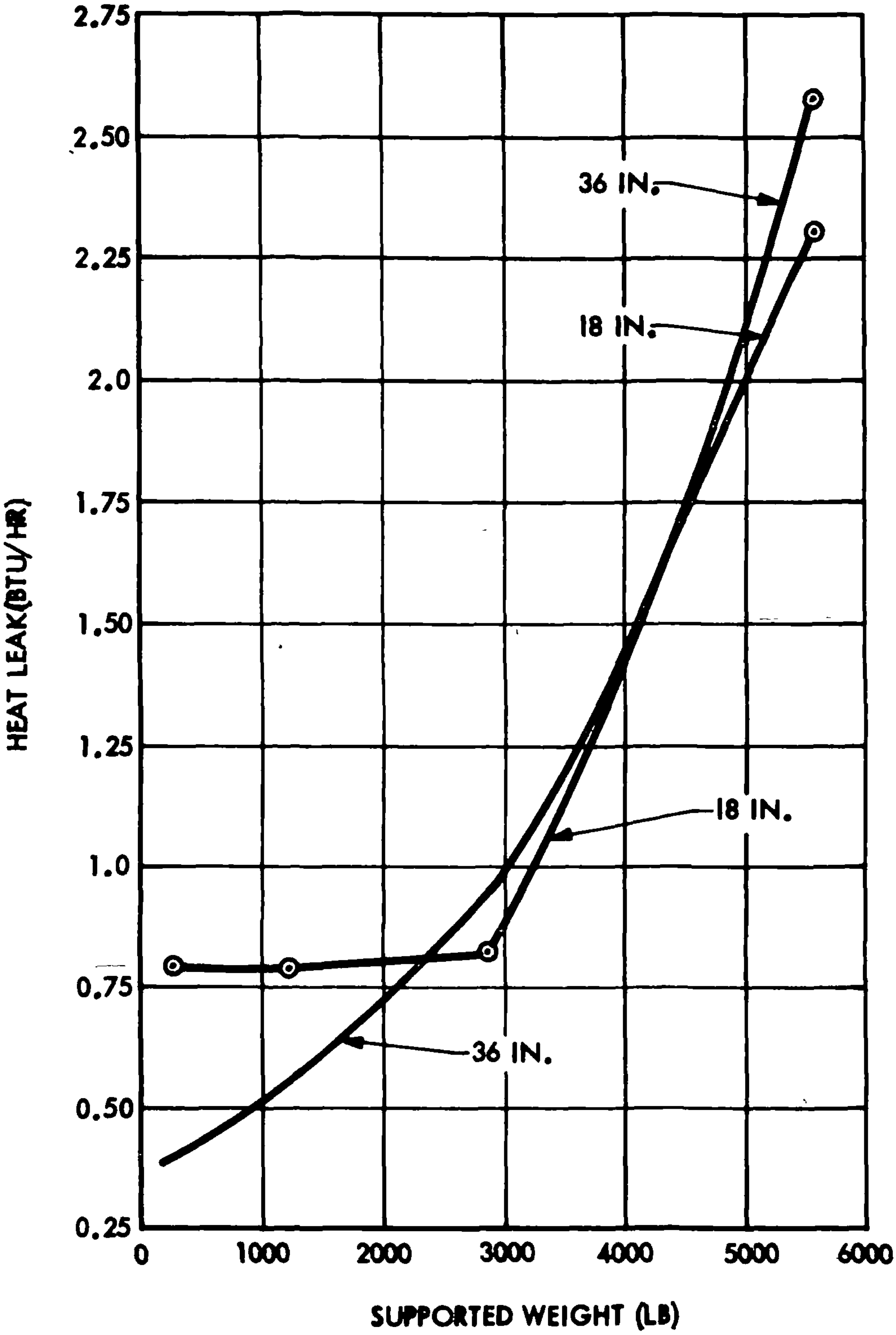

Fig. C-12 Titanium Strut Heat Leak Liquid Hydrogen (Boundary Temp. 400°R) Six Struts

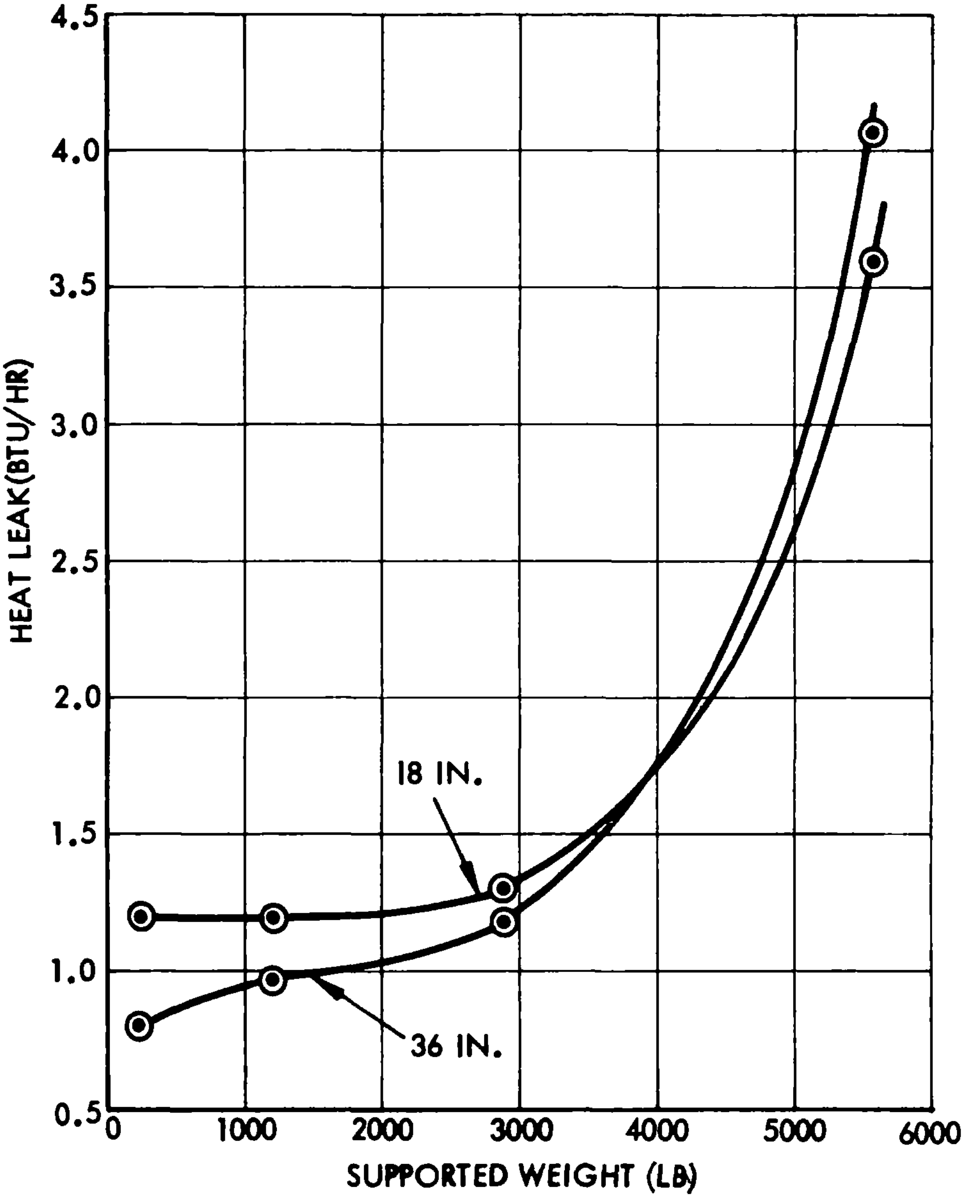

Fig. C-13 Titanium Strut Heat Leak Liquid Hydrogen (Boundary Temperature 520°R) Six Struts

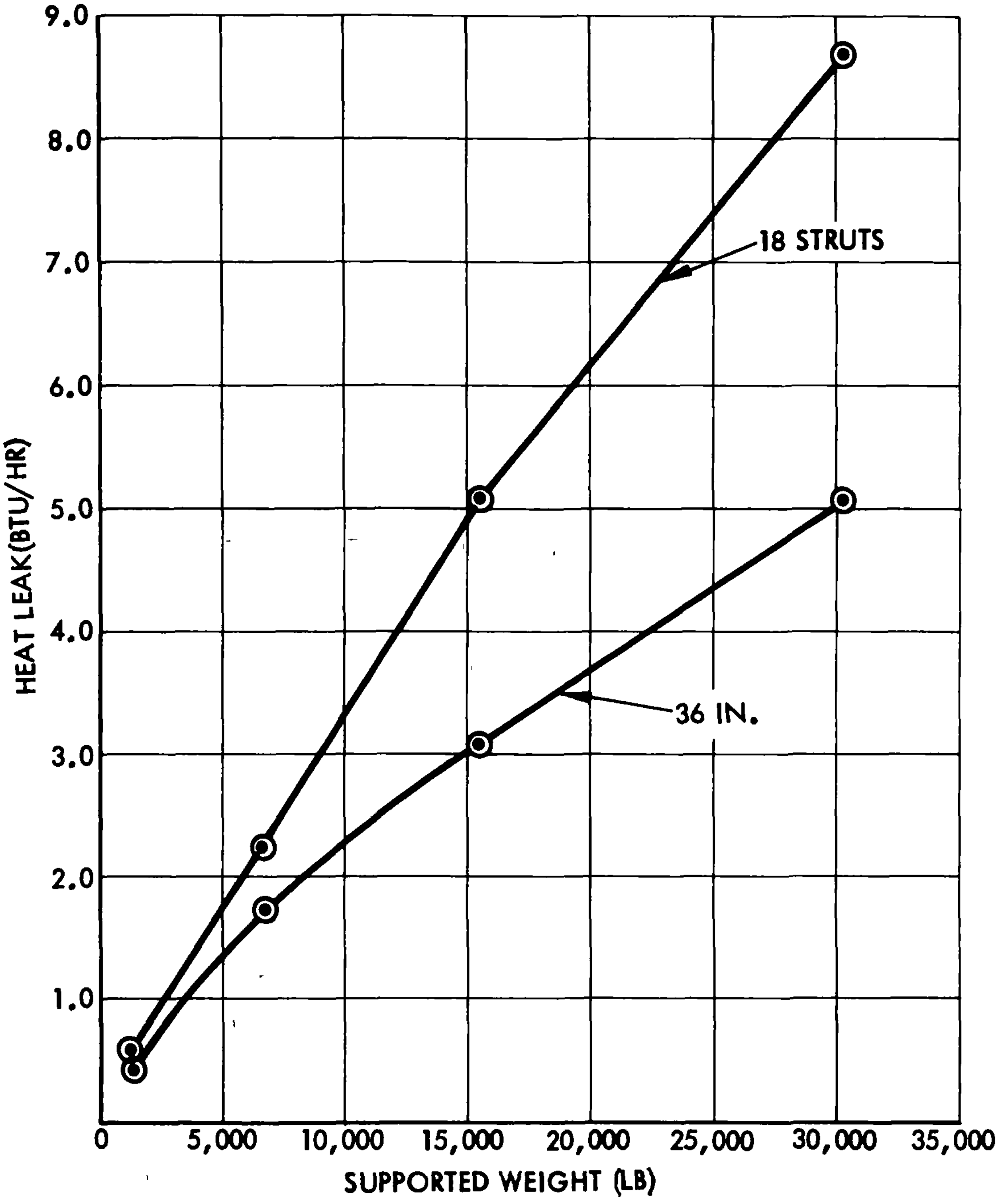

Fig. C-14 Titanium Strut Heat Leak Liquid Oxygen (Boundary Temperature 400°R) Six Struts

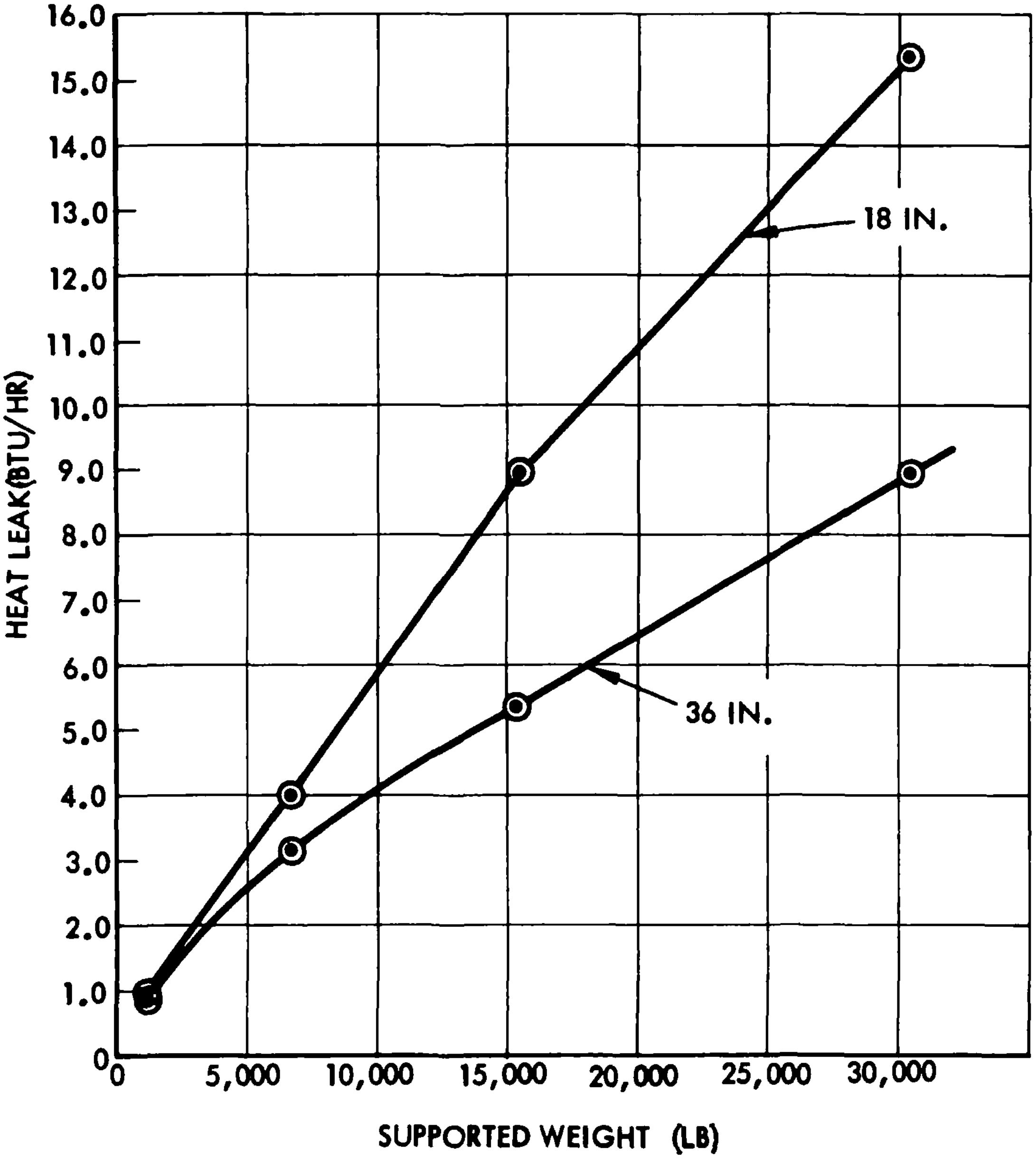

Fig. C-15 Titanium Heat Leak Liquid Oxygen
(Boundary Temperature 520°R) Six Struts

In the oxygen tank runs, it was assumed that all liquid is expelled during the last engine firing so that the final ullage condition is as it exists after the expulsion without any mixing of liquid and vapor. In the hydrogen tank runs, a liquid residual of 100 pounds was assumed prior to mixing of the tank contents following the last engine firing.

Results

Tables C-1 through C-4 summarize the parametric values included in the study. The tank geometries are given in Tables C-5 and C-6. Propellant usage profiles for the third and seventeenth revolution rendezvous missions are shown in Table C-7. Tables C-8 through C-11 include a tabulation of results from the computer analyses. Figures C-16 through C-39 show boiloff, pressurant, and residual weights plotted as a function of the listed variables.

Oxygen Tanks -- Helium Pressurization

Figures C-16 through C-22 show results for helium pressurization of the OMS oxygen tanks, and Figures C-16 through C-19 are for the case of cooled, non-vented tanks. The pressurant requirement decreases with increasing pressurant temperature because of the decreased density and increased ullage heating effect with increasing temperature. Residual vapor weight increases with increasing temperature, because the partial oxygen pressure increases to a higher final value. This pressure increase has a larger effect than the density reduction due to the temperature increase. The helium requirement increases with increasing tank pressure. Residual oxygen-vapor weight increases initially with increasing tank pressure and then gradually decreases as the effect of final oxygen partial pressure increase becomes less significant than the effect of the ullage temperature increase. However, the total variation is small, being less than 8 percent.

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Table C-1

PARAMETRIC VALUES FOR PRESSURIZATION COMPUTATIONS

Run No.	Propellant	Tank Configuration No.	Pressurant	Ullage Pressure (psia)	Pressurant Temperature (°R)	Insulation Thickness (inches)	Vent Pressure (psia)	Duty Cycle (rev.)
1	Oxygen	3	Helium	38	550	Cooled*	N.V.**	3
2				38	165			
3				38	350			
4				25				
5				50		Cooled	N.V.	
6				38		0.25	36	
7						0.75	36	
8						1.25	36	
9						0.75	38	
10		3					34	
11		2					38	
12		1				0.75	38	3
13		3			350	Cooled	N.V.	17
14					165			17
15				38	550			17
16				150	550			3
17				150	350			3
18	Oxygen	3	Helium	150	165	Cooled	N.V.	3

*Heat through insulation and penetrations is assumed intercepted by hydrogen boiloff vapor.

**Tank is nonvented.

Table C-2

PARAMETRIC VALUES FOR PRESSURIZATION CUMPUTATIONS

Run No.	Propellant	Tank Configuration No.	Pressurant	Ullage Pressure (psia)	Pressurant Temperature (^{O}R)	Insulation Thickness (inches)	Vent Pressure (psia)	Duty Cycle (rev.)
19	Oxygen	3	Oxygen	38	550	Cooled*	N.V.**	3
20				38	165			
21				38	350			
22				25				
23				50		Cooled		
24				38		0.25		
25						0.75		
26		3				1.25		3
27		2				0.75		2
28		1				0.75		1
29		3			350	Cooled		3
30		3			165			3
31	Oxygen	3	Oxygen	38	550	Cooled	N.V.	3

*Heat through insulation and penetration is intercepted by hydrogen boiloff.

**Tank is non-vented.

Table C-3

PARAMETRIC VALUES FOR PRESSURIZATION CALCULATIONS

Run No.	Propellant	Tank Configuration No.	Pressurant	Ullage Pressure (psia)	Pressurant Temperature (°R)	Insulation Thickness (inches)	Vent Pressure (psia)	Duty Cycle (rev.)
32	Hydrogen	3	Helium	28	550	0.75	23	3
33				28	165		23	
34				28	350		23	
35				20			17	
36				36		0.75	31	
37				28		0.25	23	
38		3				1.25		
39		2				0.75		
40		1						3
41		3			350			17
42					165			17
43				28	550		23	17
44				36	350		25	3
45	Hydrogen	3	Helium	36	350	0.75	28	3

Table C-4

PARAMETRIC VALUES FOR PRESSURIZATION CALCULATIONS

Run No.	Propellant	Tank Configuration No.	Pressurant	Ullage Pressure (psia)	Pressurant Temperature (°R)	Insulation Thickness (inches)	Vent Pressure (psia)	Duty Cycle (rev.)
46	Hydrogen	3	Hydrogen	28	550	0.75	23	3
47				28	165		23	
48				28	350		23	
49				20			17	
50				36		0.75	31	
51				28		0.25	23	
52		3				1.25		
53		2				0.75		
54		1						3
55		3			350			17
56					165			17
57				28	550		23	17
58				36	350		25	3
59	Hydrogen	3	Hydrogen	36	350	0.75	28	3

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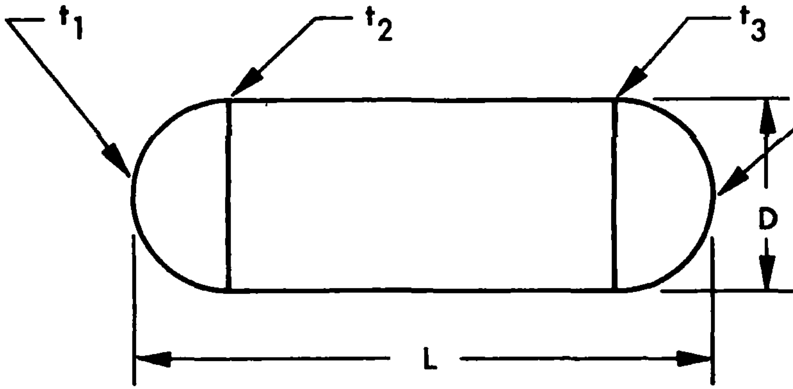
Table C-5

OMS OXYGEN TANK CONFIGURATIONS

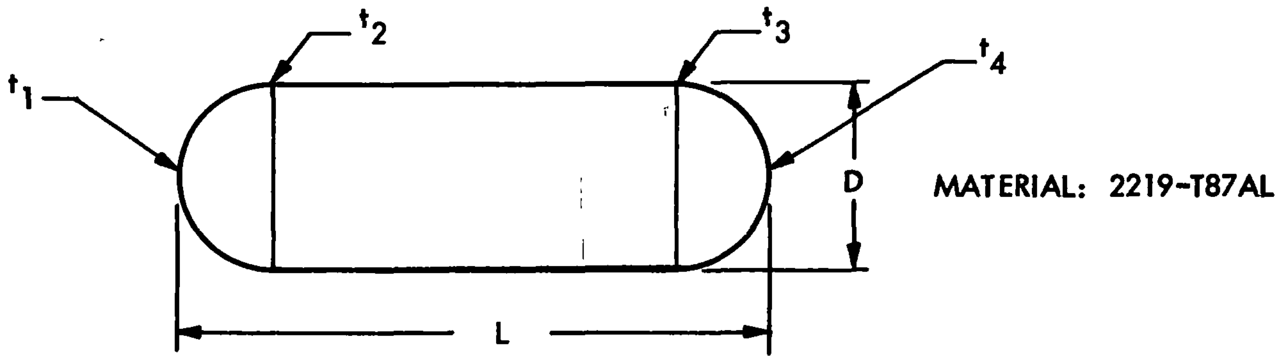


MATERIAL: 2219-T87AL

Configuration No.	L (ft)	D (ft)	Tank Surface Area (ft^2)	Tank Volume (ft^3)	Tank Ullage Pressure (psia)	Tank Weight (lbs)	Tank Wall Thickness (inches)			
							t_1	t_2	t_3	t_4
1	24.2	5.0	380.1	442.4	25	219.2	.025	.025	.044	.025
1	24.2	5.0	380.1	442.4	50	324.9	.025	.045	.065	.034
2	13.8	7.0	303.5	441.3	25	175.3	.025	.032	.044	.025
2	13.8	7.0	303.5	441.3	50	210.9	.032	.064	.072	.039
3	9.5	9.5	284.0	449.0	25	115.0	.025	.025	.025	.026
3	9.5	9.5	284.0	449.0	50	197.0	.040	.043	.043	.048

Table C-6

OMS HYDROGEN TANK CONFIGURATIONS



Configuration No.	L (ft)	D (ft)	Tank Surface Area (ft^2)	Tank Volume (ft^3)	Tank Ullage Pressure (psia)	Tank Weight (lbs)	Tank Wall Thickness (inches)			
							t_1	t_2	t_3	t_4
1	34.5	8.0	867.3	1600.5	20	437.2	.025	.028	.028	.025
1	34.5	8.0	867.3	1600.5	35	663.7	.025	.049	.049	.025
2	17.9	11.7	692.0	1605.0	20	373.4	.025	.038	.038	.025
2	17.9	11.7	692.0	1605.0	35	567.4	.033	.066	.066	.033
3	14.5	14.5	664.0	1605.2	20	313.0	.025	.025	.025	.025
3	14.5	14.5	664.0	1605.2	35	520.0	.044	.044	.044	.044

Table C-7

OMS PROPELLANT USAGE PROFILE

Event	3rd Rev Rendezvous				17th Rev Rendezvous			
	Mission Elapsed Time (hr)	Burn Time (sec)	LH_2 Used (lb)	LO_2 Used (lb)	Mission Elapsed Time (hr)	Burn Time (sec)	LH_2 Used (lb)	LO_2 Used (lb)
Phasing	0.83	207	1180	5920	0.83	76	435	2185
Height	1.58	160	917	4583	22.23	165	940	4700
Coelliptic	2.37	20	114	571	23.00	137	780	3910
TPI	3.85	12	70	352	24.58	12	70	354
Contingency	156.5	127	725	3625	156.5	125	710	3570
Deorbit	167.0	279	1590	7960	167.0	279	1590	7950

Propellant requirements are based on: 15,000 lb. thrust
439 sec. specific impulse
5.7 lb/sec. hydrogen flow rate
28.6 lb/sec. oxygen flow rate

Table C-8

PRESSURIZATION RESULTS FOR HELIUM PRESSURIZATION OF OMS OXYGEN TANKS

Run No.	Final Ullage Temperature (^{o}R)	Oxygen Partial Pressure (psia)	Helium Partial Pressure (psia)	Boiloff Weight (lbs)	Residual Vapor Weight (lbs)	Pressurant Weight (lbs)	Total Weight* (lbs)
1	200	15.6	22.4	0	106	18.8	125
2	165	11.5	26.5		96	25.0	121
3	186	14.1	23.9		104	21.7	126
4	185	13.2	11.8		98	10.1	108
5	186	14.3	35.7	0	106	32.1	138
6	192	12.3	25.7	538	87	22.5	648
7	188	12.6	25.4	219	91	22.6	333
8	187	12.7	25.3	156	92	22.7	271
9	184	14.6	23.4	195	108	20.2	323
10	192	8.5	29.5	222	60	25.7	308
11	184	14.2	23.8	204	104	20.3	328
12	183	14.1	23.9	257	104	20.5	382
13	185	13.7	24.3	0	101	22.1	123
14	164	11.2	26.8		95	25.1	120
15	199	14.8	23.2		101	19.6	121
16	210	15.9	134.1		103	105.2	208
17	190	14.4	135.6		103	117.5	221
18	164	11.2	138.8	0	95	137.2	232

*Sum of boiloff, residual and pressurant weights.

Table C-9

PRESSURIZATION RESULTS FOR OXYGEN PRESSURIZATION OF OMS OXYGEN TANKS

Run No.	Final Ullage Temperature (^{o}R)	Final Ullage Pressure (psia)	Minimum Δ p* (psia)	Residual Vapor Weight (lbs)	Pre-Pressurant Weight (lbs)	Expulsion Pressurant Weight (lbs)	Total Weight** (lbs)
19	256	38.0	17.9	199	237	90	526
20	166	38.0	18.4	306	593	241	1140
21	222	38.0	16.5	230	313	127	670
22	206	25.0	6.8	163	124	87	374
23	231	50.0	25.1	291	484	167	942
24	210	38.0	7.4	243	249	128	620
25	217		13.2	235	290	128	653
26	219		14.3	233	297	127	657
27	216		13.0	232	285	130	647
28	212		11.9	237	287	135	659
29	223		17.0	229	298	123	650
30	166		18.8	307	558	241	1106
31	258	38.0	18.2	198	226	91	515

*Difference between tank operating pressure and maximum liquid saturation pressure.
**Sum of residual and pressurant weights.

Table C-10

PRESSURIZATION RESULTS FOR HELIUM PRESSURIZATION OF OMS HYDROGEN TANKS

Run No.	Final Ullage Temperature (°R)	Hydrogen Partial Pressure (psia)	Helium Partial Pressure (psia)	Optimum Propellant Load (lbs)	Boiloff Weight (lbs)	Residual Vapor Weight (lbs)	Pressurant Weight (lbs)	Total Weight* (lbs)
32	53.9	22.9	5.1	4938	227	138	43.5	409
33	49.2	14.5	13.5	4953	271	110	126.0	507
34	52.6	20.5	7.5	4941	236	130	65.3	431
35	49.1	15.3	4.7	4941	266	103	44.4	413
36	52.9	25.6	10.4	4923	178	168	89.8	436
37	52.7	20.6	7.4	5269	568	131	64.1	763
38	52.6	20.5	7.5	4877	172	130	65.6	368
39	52.6	20.5	7.5	4948	245	131	65.2	441
40	52.7	20.5	7.5	5002	298	131	65.1	494
41	52.7	20.6	7.4	4918	213	131	64.0	408
42	49.3	14.6	13.4	4938	252	111	124.6	488
43	54.0	23.0	5.0	4915	202	138	42.5	383
44	61.2	23.4	12.6	5014	307	132	94.1	533
45	56.5	24.7	11.3	4968	247	150	91.1	488

*Sum of boiloff, residual and pressurant weights.

Table C-11

PRESSURIZATION RESULTS FOR HYDROGEN PRESSURIZATION OF OMS HYDROGEN TANKS

Run No.	Final Ullage Temperature (°R)	Final Ullage Pressure (psia)	Optimum Propellant Load (lbs)	Boiloff Weight (lbs)	Residual Vapor Weight (lbs)	Pre-Pressurant Weight (lbs)	Expulsion Pressurant Weight (lbs)	Total Weight* (lbs)
46	55.5	28.0	4948	218	158	4.7	10.7	391
47	52.7	28.0	4968	227	168	14.7	35.0	445
48	54.7	28.0	4953	220	161	7.2	16.7	405
49	51.1	20.0	4938	243	122	2.4	14.1	382
50	54.9	36.0	4956	173	210	11.6	21.4	416
51	54.6	28.0	5284	553	161	6.4	16.8	737
52	54.8		4892	155	161	7.4	16.7	340
53	54.7		4961	228	161	7.2	16.7	413
54	54.7		5014	282	161	7.1	16.6	467
55	54.8		4929	193	161	5.2	21.5	381
56	52.7		4941	199	168	13.1	35.1	415
57	55.5	28.0	4923	191	158	4.2	10.8	364
58	64.0	36.0	5030	280	176	14.2	20.9	491
59	58.9	36.0	4991	226	193	12.8	21.1	453

*Sum of boiloff, residual and pressurant weights.

NOMENCLATURE

p_{EXP}	expulsion pressure (psia)
p_v	vent pressure (psia)
Q	heat rate into tank through insulation and penetrations (Btu/hr)
T_p	pressurant temperature (°R)
W_{BO}	boiloff weight (lb)
W_{EXP}	expulsion pressurant weight (lb)
W_{GH_2}	residual gaseous hydrogen weight (lb)
W_{He}	helium pressurant weight (lb)
W_{PP}	pre-pressurization pressurant weight (lb)
W_{GO_2}	residual gaseous oxygen weight (lb)
3rd R.R.	third revolution rendezvous
17th R.R.	seventeenth revolution rendezvous

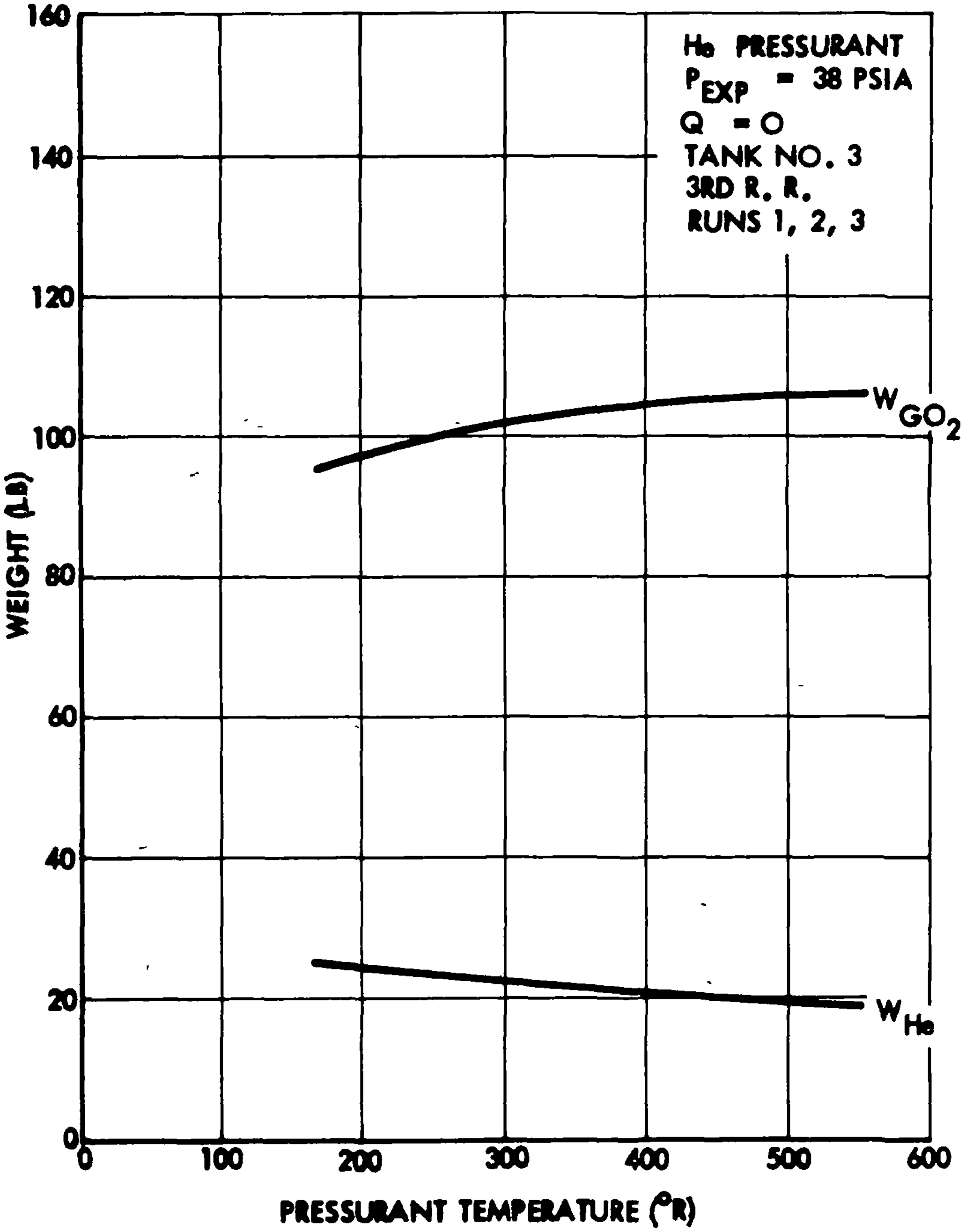


Fig. C-16 OMS LO_2 Tanks - He Pressurant and Oxygen Residual Weights Vs Pressurant Temperature

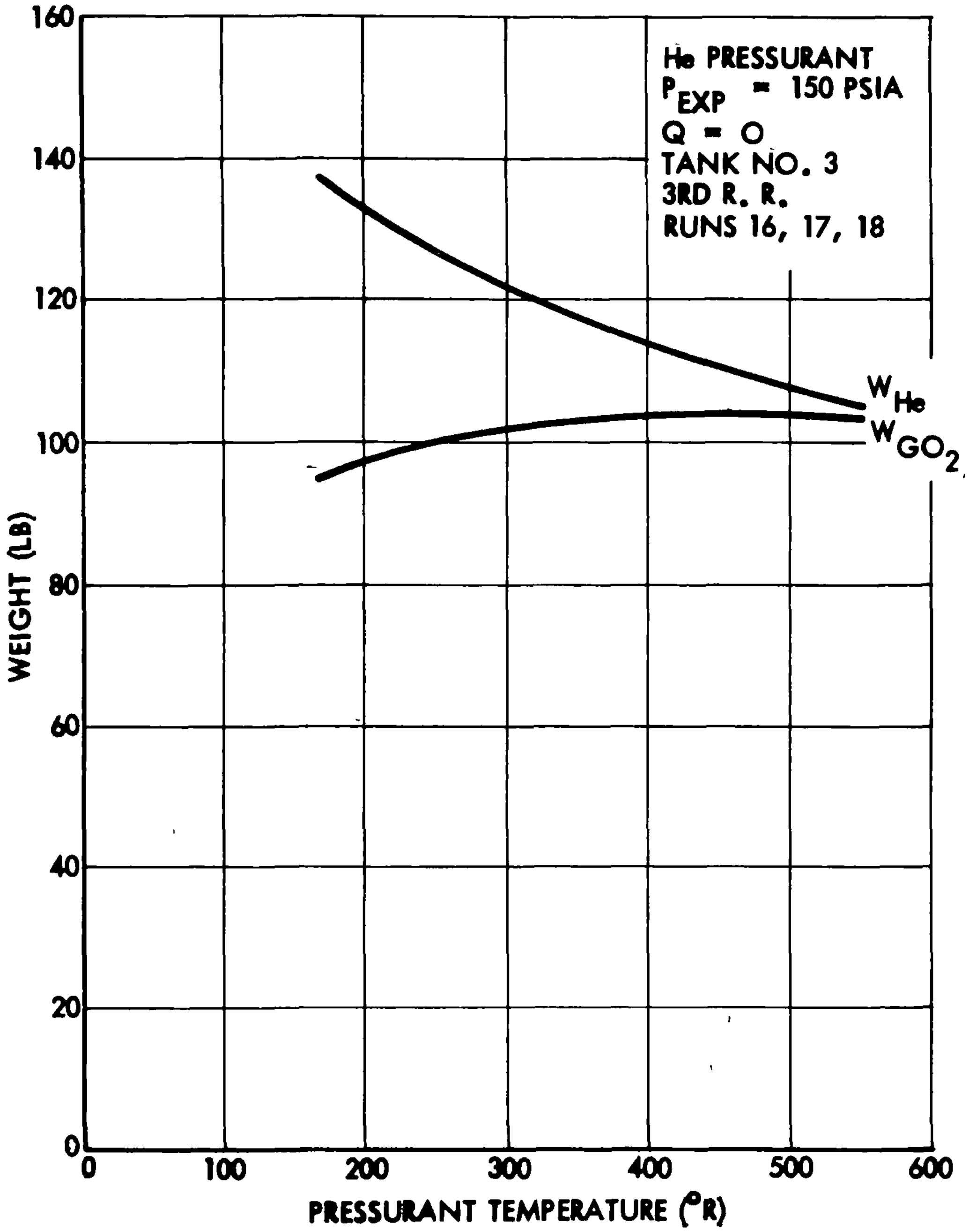


Fig. C-17 OMS LO_2 Tanks - He Pressurant and Oxygen Residual Weights Vs Pressurant Temperature

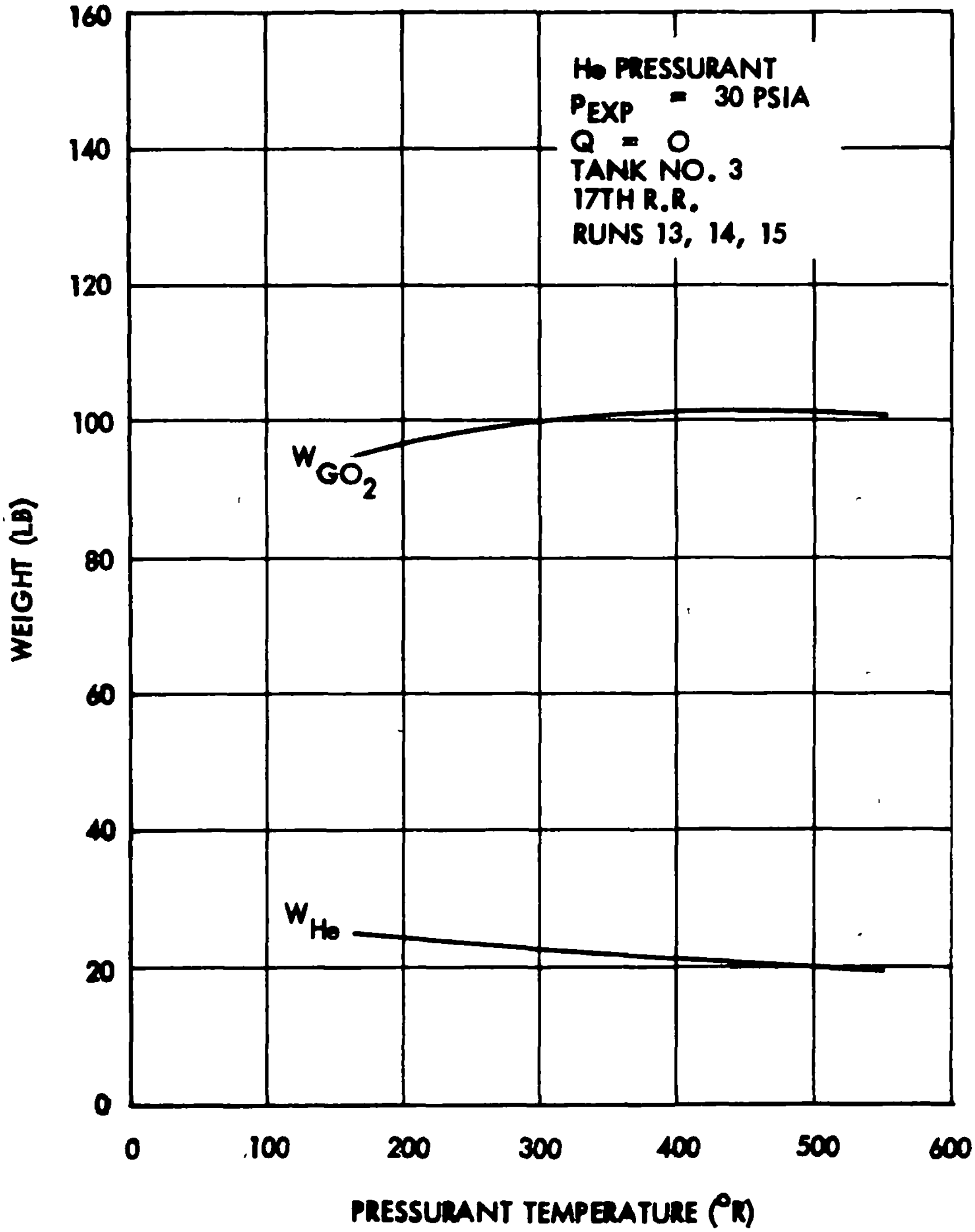


Fig. C-18 OMS LO_2 Tanks - He Pressurant and Oxygen Residual Weights Vs Pressurant Temperature

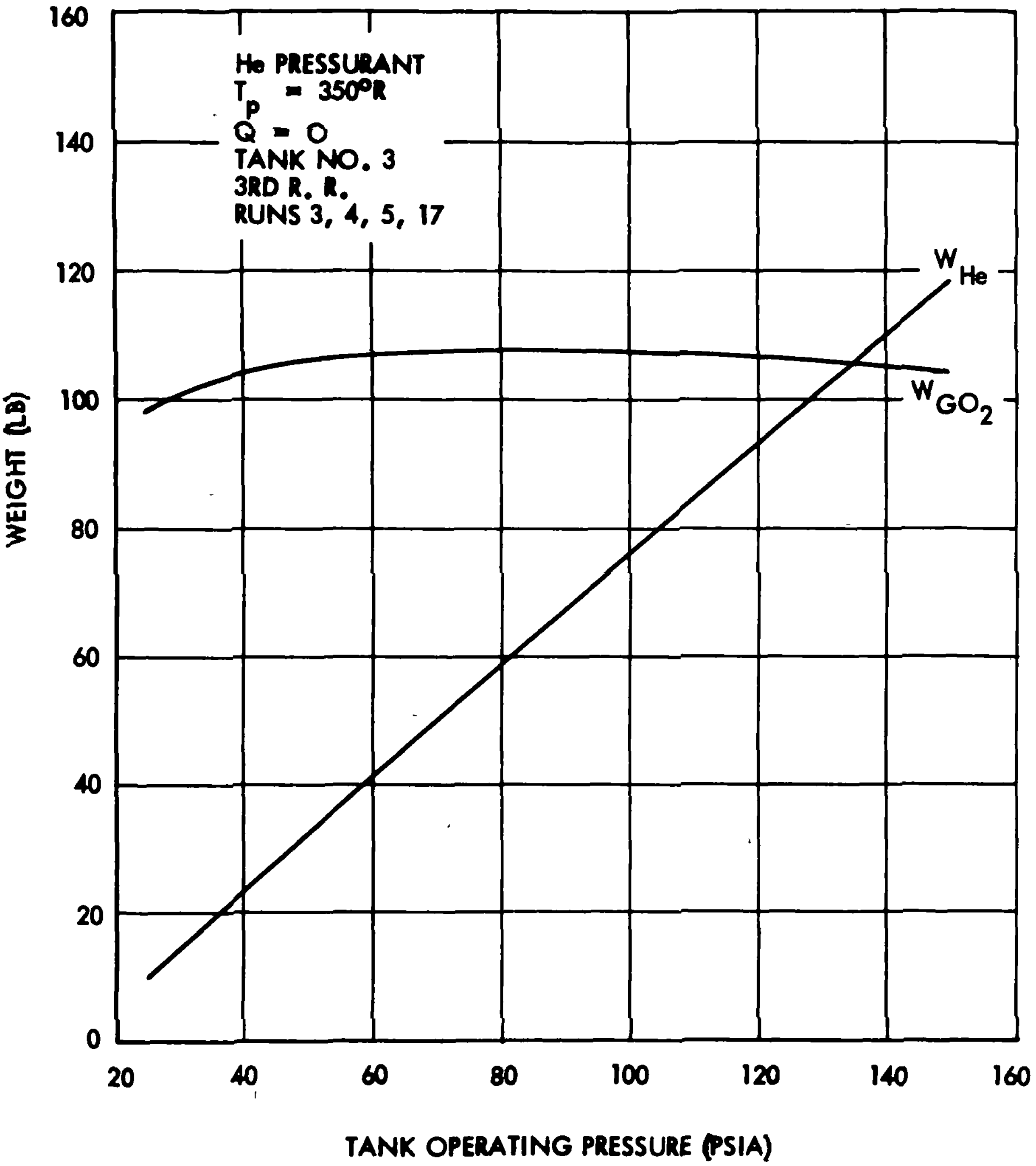


Fig. C-19 OMS LO_2 Tanks - He Pressurant and Oxygen Residual Weights Vs Tank Operating Pressure

Figures C-20, C-21, and C-22 are for the case of noncooled, vented tanks. The most significant effect of insulation thickness is the increase in boiloff weight with decreasing insulation thickness (Fig. C-20). The vent pressure effect is shown in Figure C-21. As the vent pressure increases, the helium partial pressure decreases -- resulting in a decreased helium requirement. The corresponding increased oxygen partial pressure results in an increased gaseous-oxygen residual weight. Boiloff decreases with increasing vent pressure, because the liquid absorbs heat that would otherwise result in boiloff. Figure C-22 illustrates the effect of tank geometry. As the tank area increases for a given tank volume, the increase in the heat entering the tank results in increased boiloff weight. The effect on helium requirement and residual vapor weight is negligible.

Oxygen Tanks - Oxygen Vapor Pressurization

In Figures C-23 through C-27, prepressurant, expulsion pressurant, and residual vapor weights are plotted as a function of the study variables. The pressurant temperature effect is shown in Figures C-23 and C-24 for the third and seventeenth revolution rendezvous missions, respectively. Prepressurant weights are slightly greater for third revolution mission because of the greater propellant usage and resulting larger ullage volume early in the mission. The expulsion pressurant and residual vapor weights are essentially the same for the two missions; the weights increase significantly with increasing tank pressure. The most significant effect of insulation thickness is on the prepressurant requirements. More heat enters the tank with less insulation -- resulting in an increased liquid temperature with higher vapor pressure. Therefore, the resulting pressure rise required during prepressurization decreases -- resulting in a decreased mass requirement. The variations due to tank geometry are slight for the range of geometries considered.

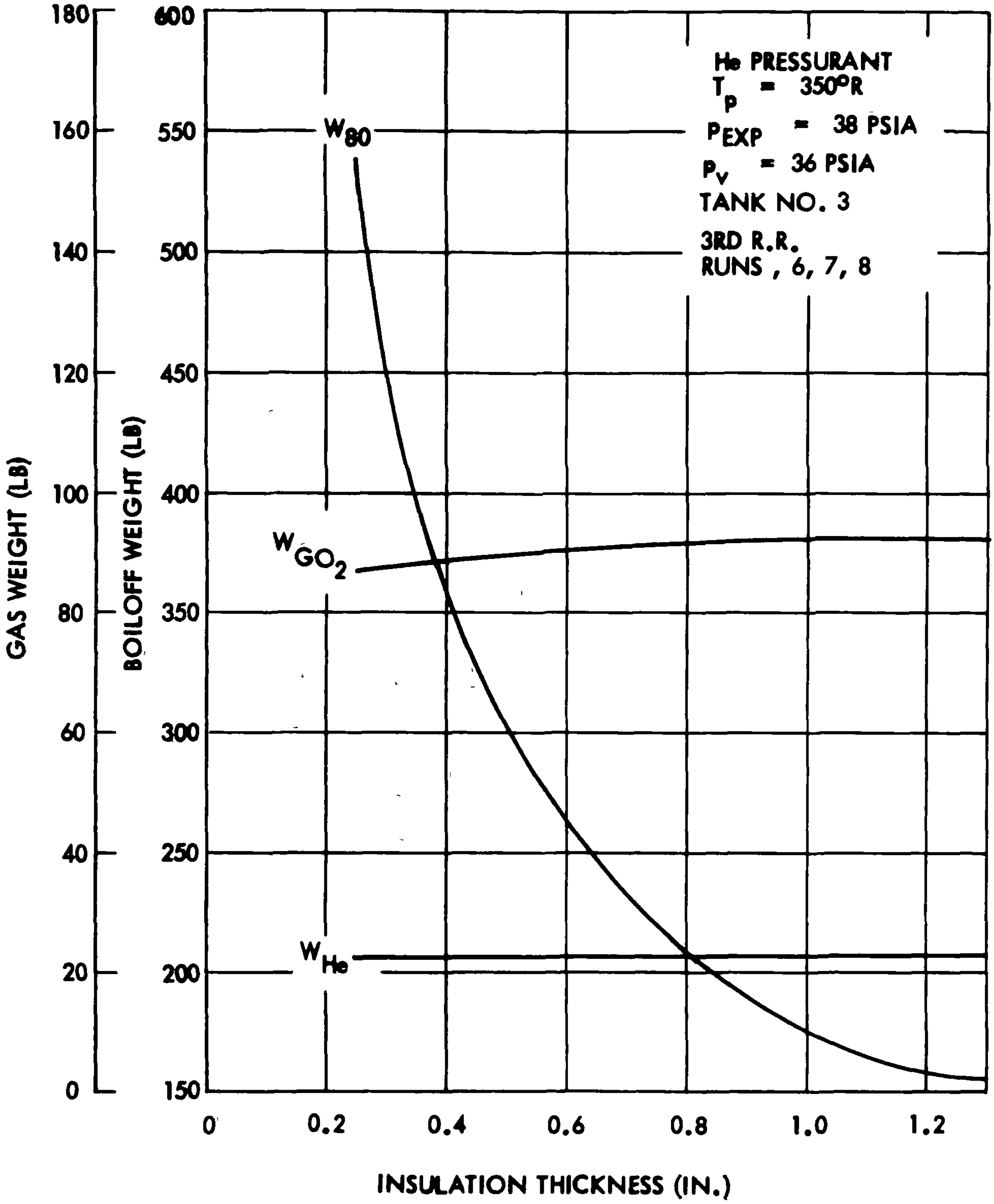


Fig. C-20 OMS LO_2 Tanks - Boiloff, He Pressurant and Oxygen Residual Weights Vs Insulation Thickness

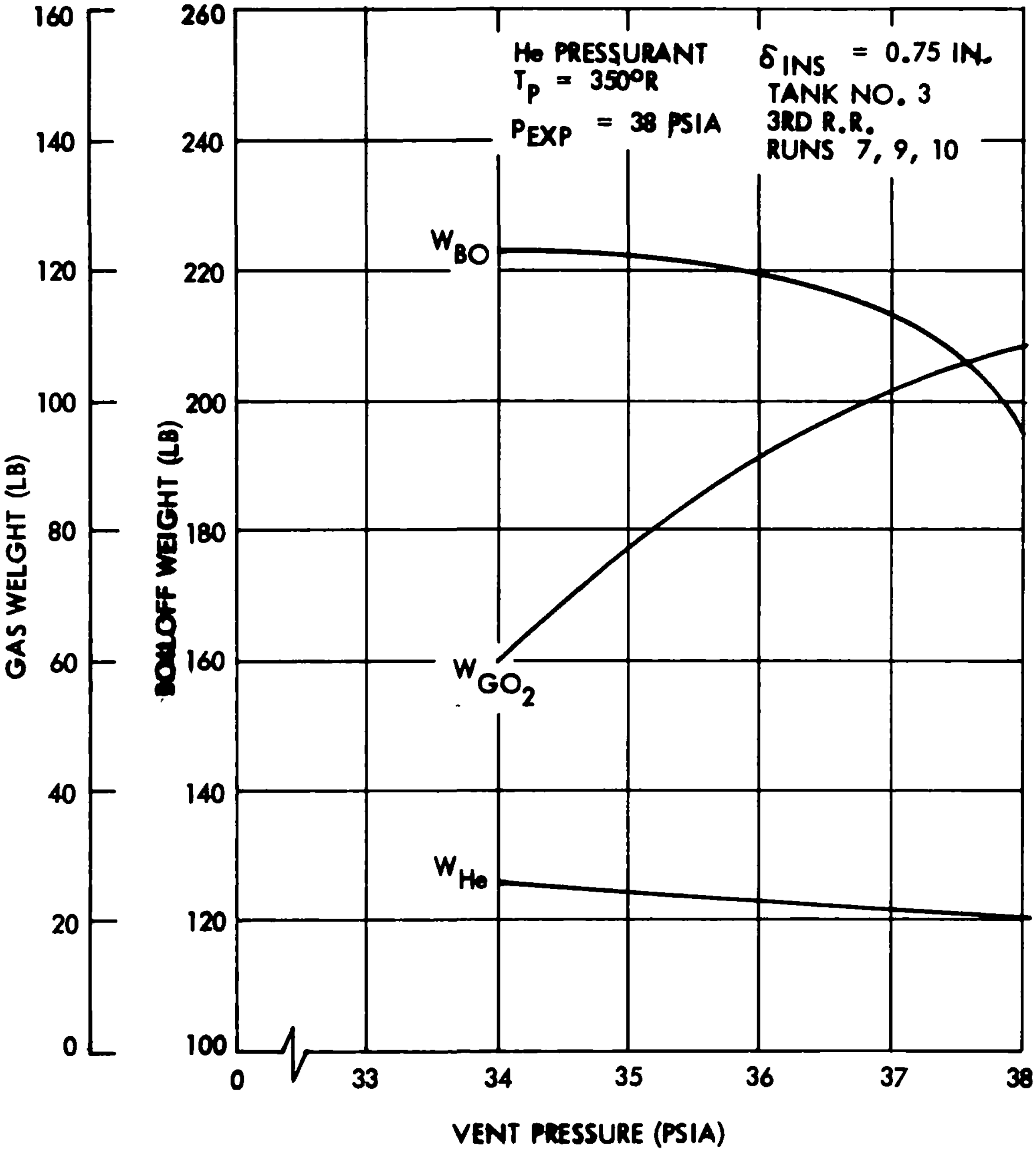


Fig. C-21 OMS LO_2 Tanks - Boiloff, He Pressurant and Oxygen Residual Weights Vs Vent Pressure

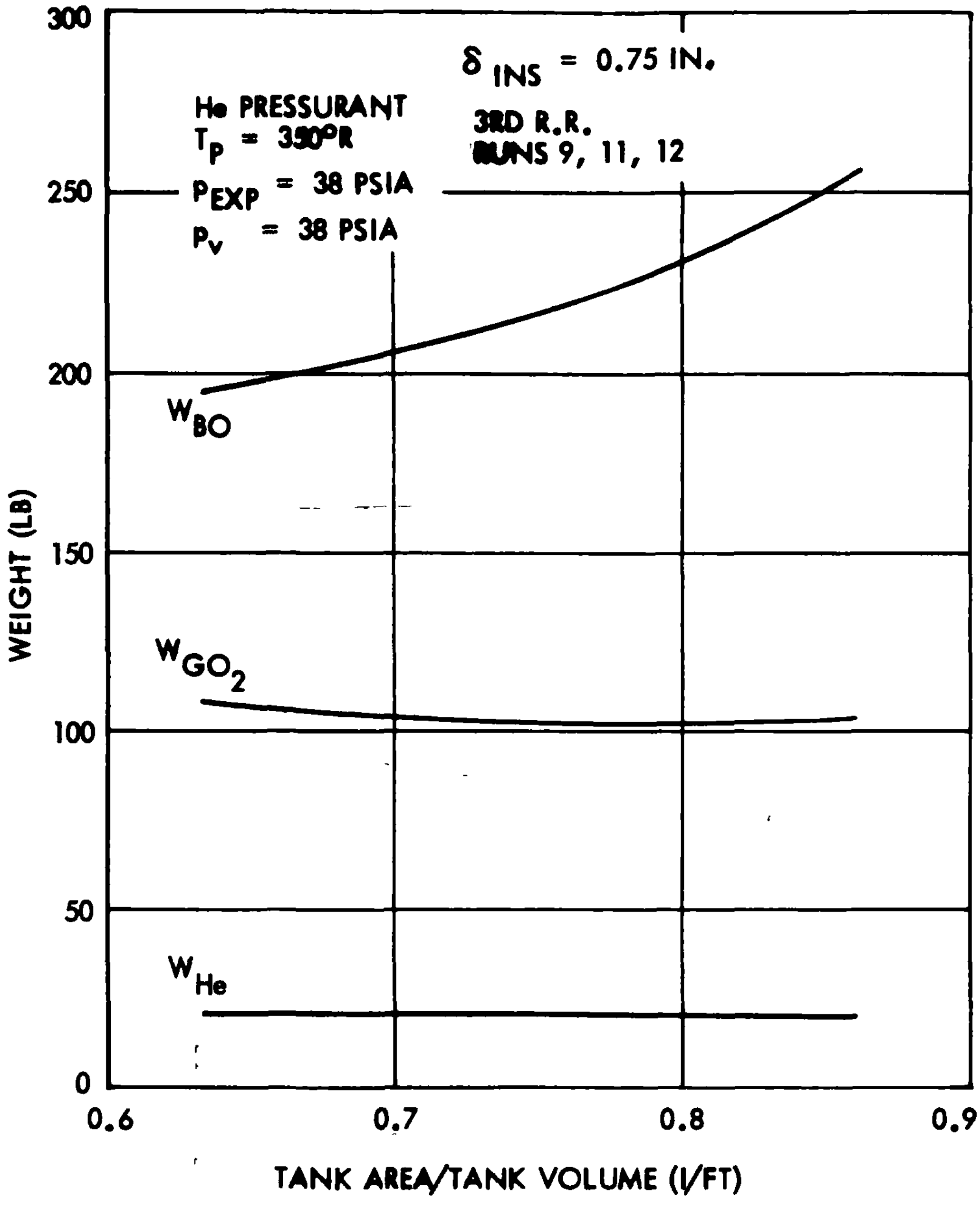


Fig. C-22 OMS LO_2 Tanks - Boiloff, He Pressurant and Oxygen Residual Weights Vs Tank Geometry

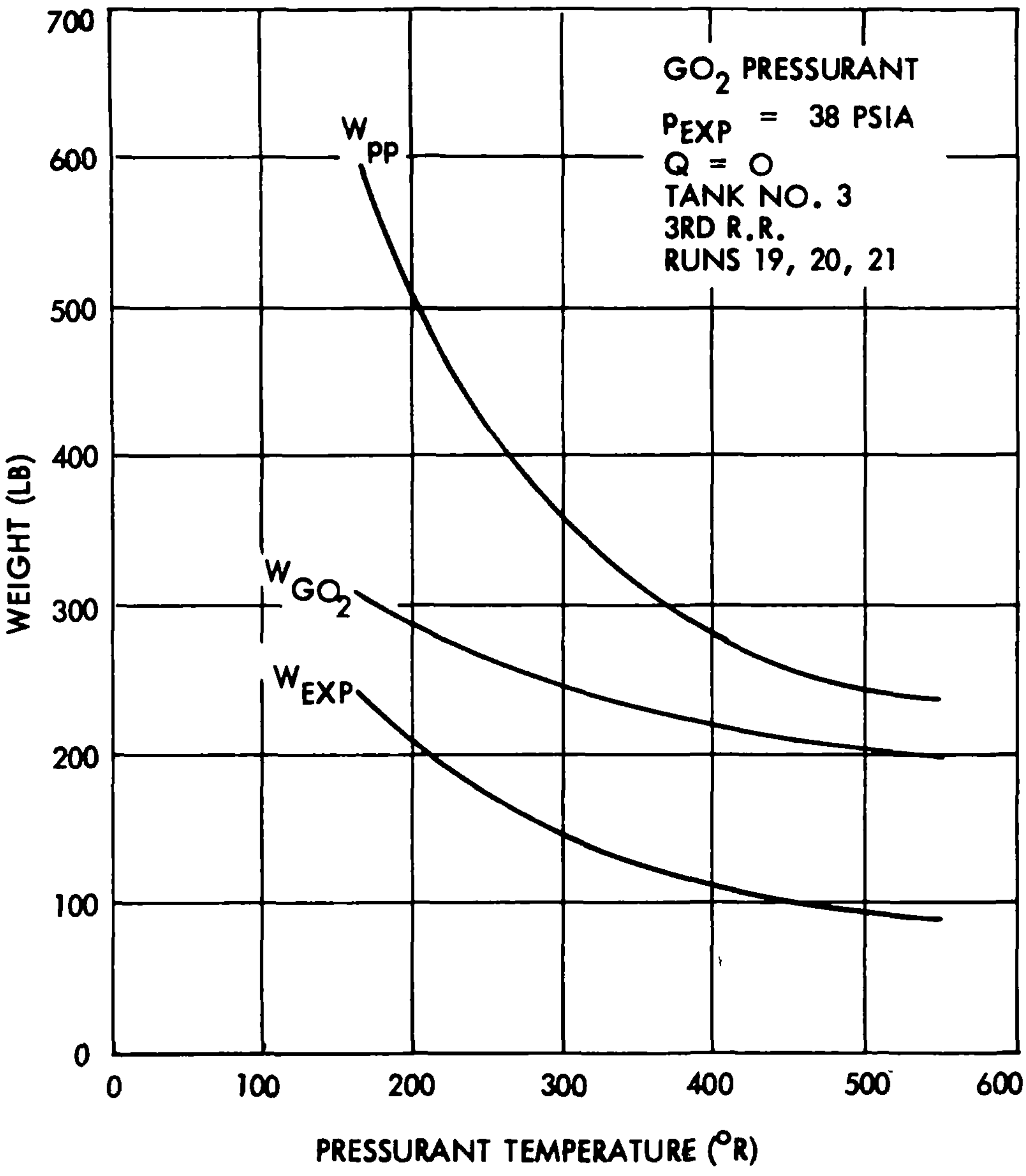


Fig. C-23 OMS LO_2 Tanks - GO_2 Pre-Pressurant, Pressurant and Residual Weights Vs Pressurant Temperature

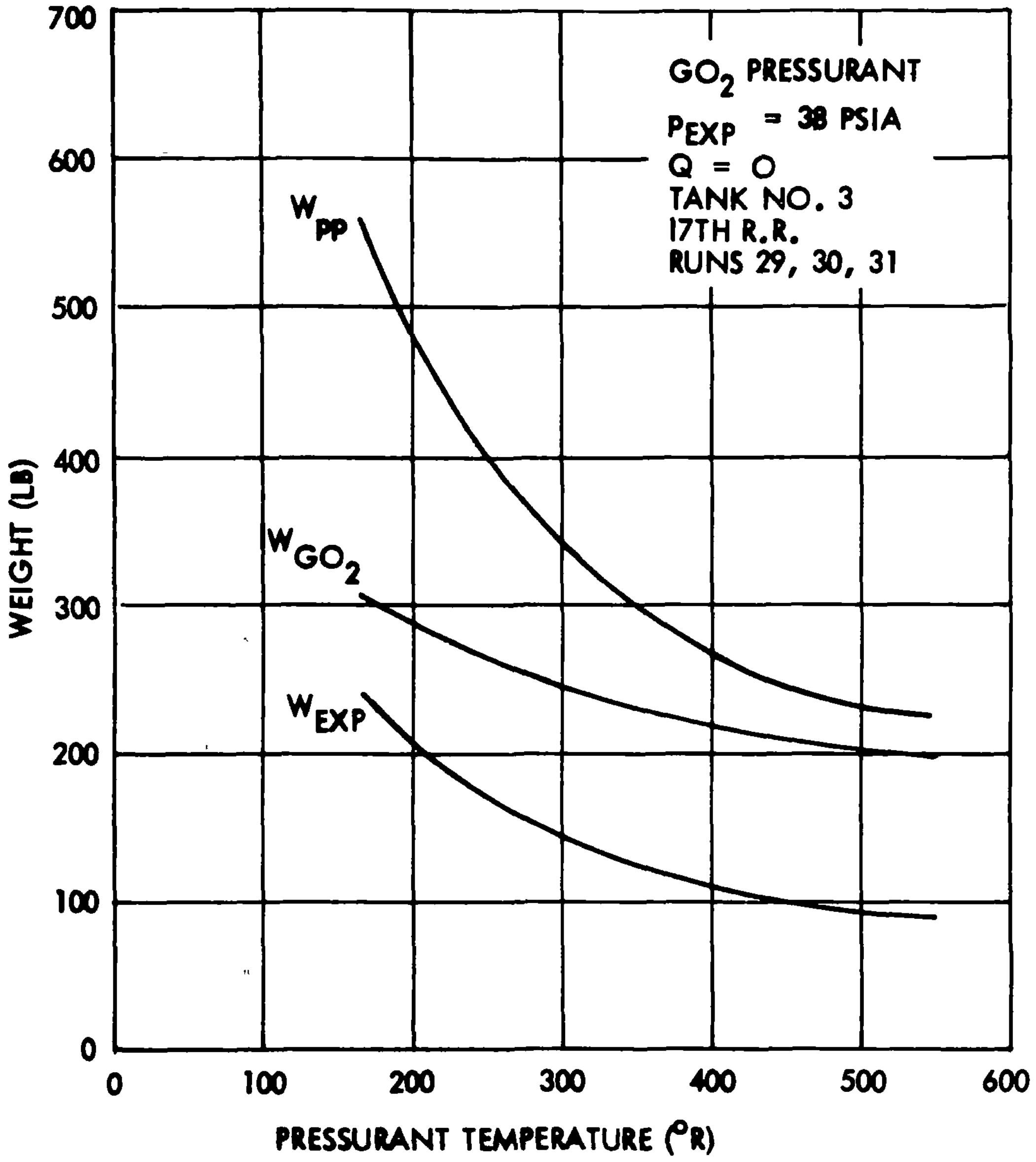


Fig. C-24 OMS LO_2 Tanks - GO_2 Pre-Pressurant, Pressurant and Residual Weights Vs Pressurant Temperature

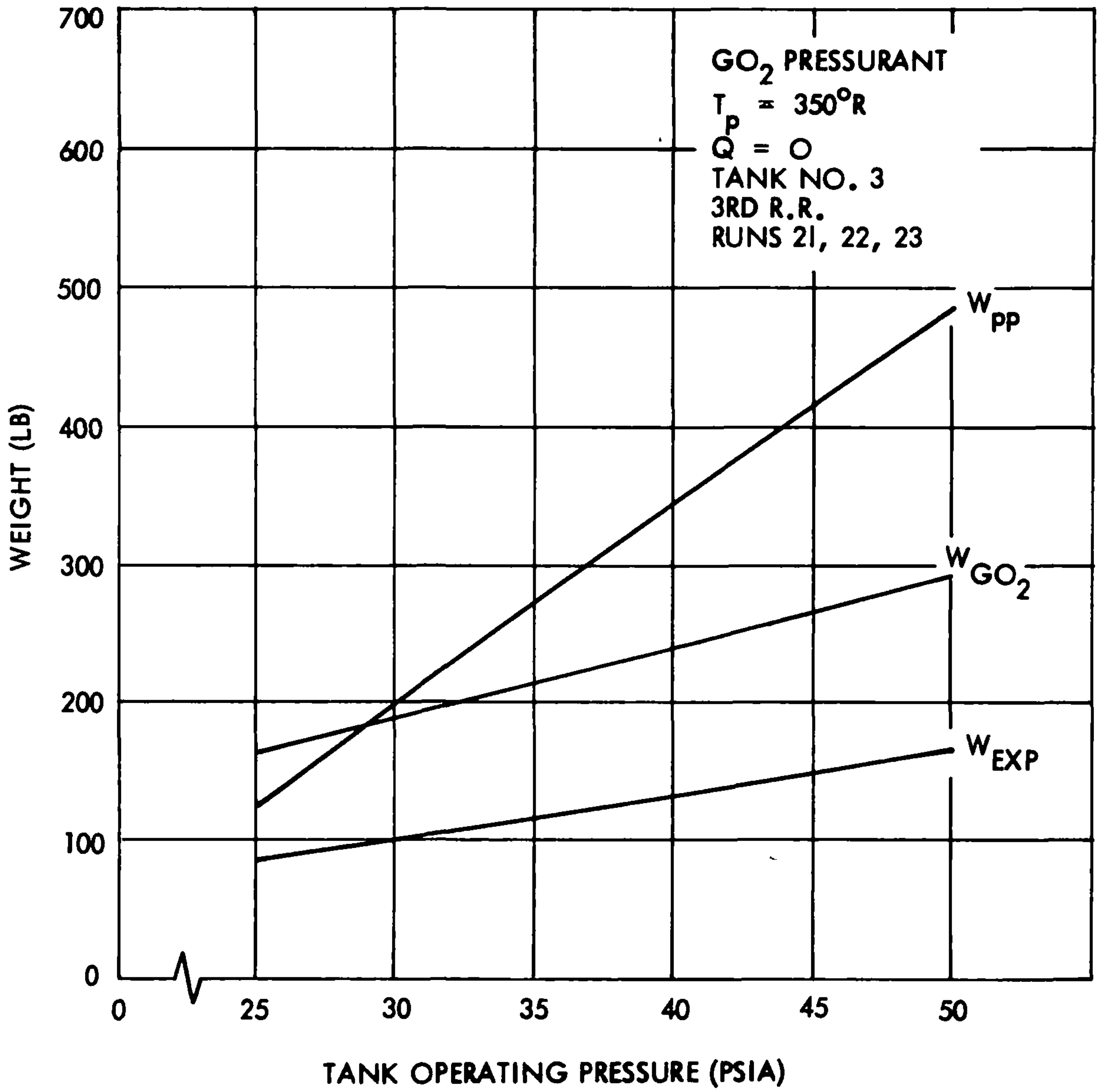


Fig. C-25 OMS LO_2 Tanks - GO_2 Pre-Pressurant, Pressurant and Residual Weights Vs Tank Operating Pressure

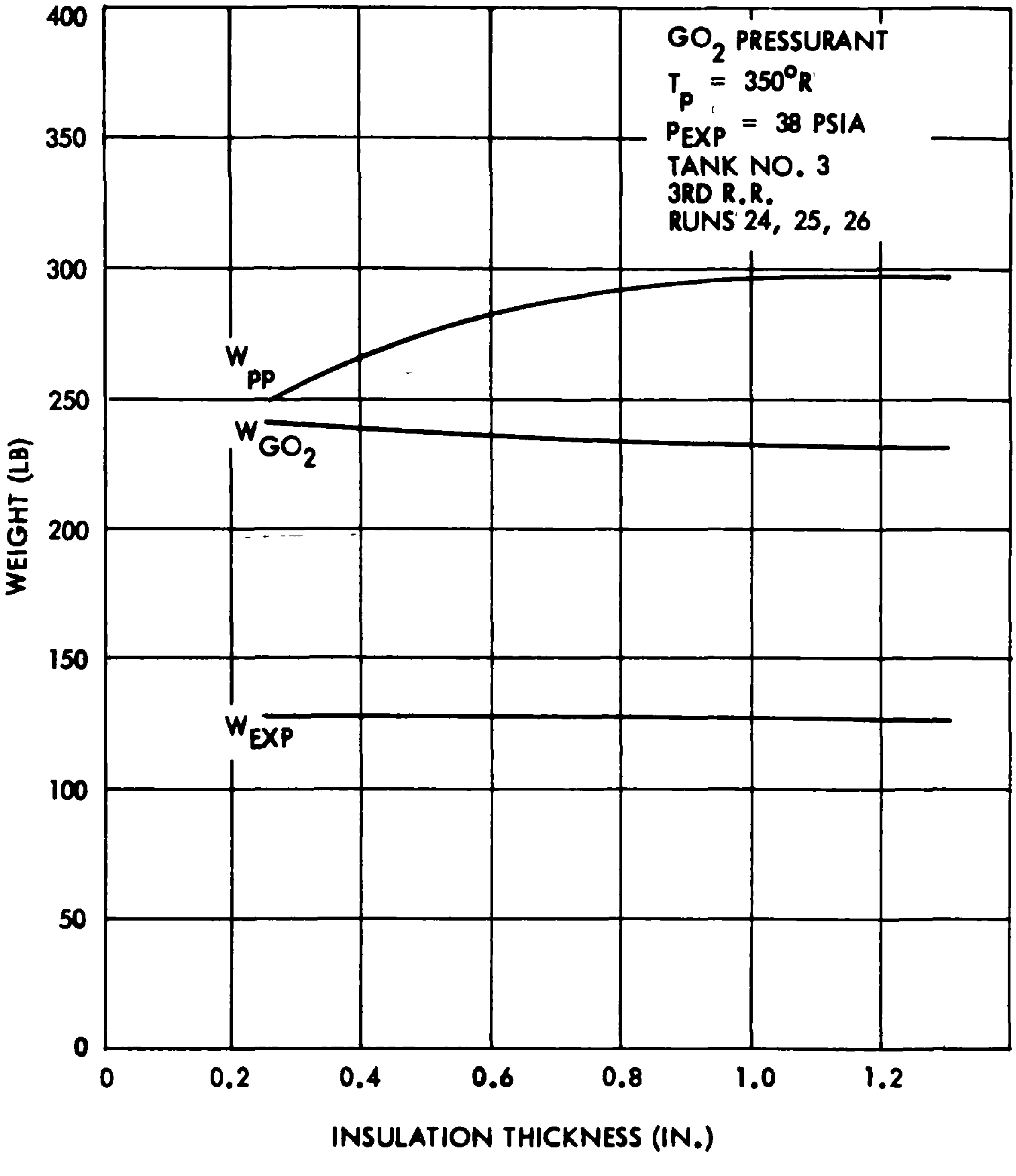


Fig. C-26 OMS LO_2 Tanks - GO_2 Pre-Pressurant, Pressurant and Residual Weights Vs Insulation Thickness

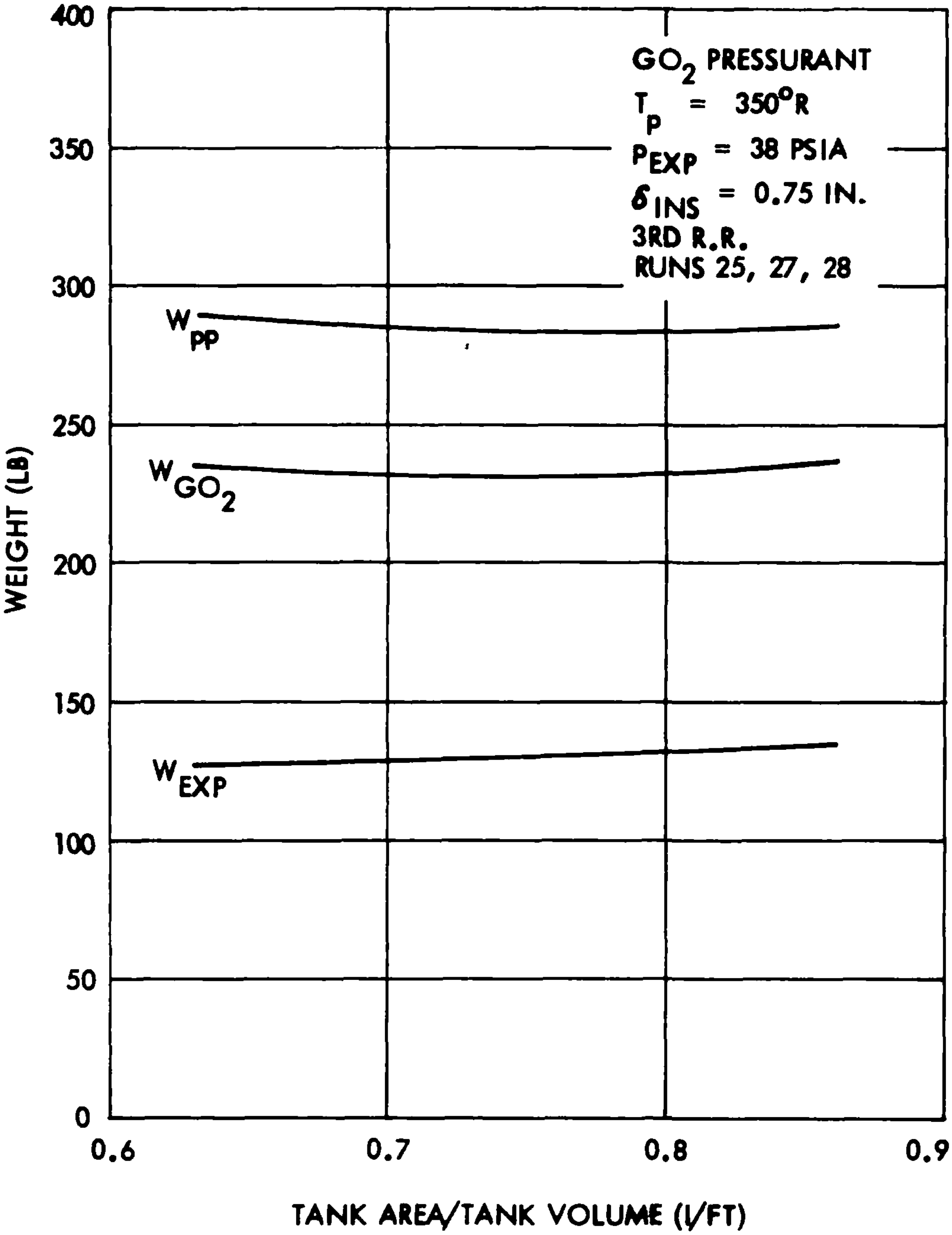


Fig. C-27 OMS LO_2 Tanks - GO_2 Pre-Pressurant, Pressurant and Residual Weights Vs Tank Geometry

Hydrogen Tanks - Helium Pressurization

Helium pressurization results are shown in Figure C-28. In all hydrogen tank runs, a liquid residual of 100 pounds was assumed to exist prior to mixing of the tank contents following the last engine firing. The computer program optimized the initial propellant load to assure the 100-lb liquid residual. These values are included in Tables C-10 and C-11.

Figures C-28 and C-29 show the effect of pressurant temperature for the third and seventeenth revolution rendezvous missions, respectively. The boiloff weight is greater for the third revolution case, because earlier propellant utilization results in less remaining liquid to absorb incoming heat. Boiloff decreases with increasing pressurant temperature, because the propellant absorbs more heat in reaching a higher final temperature. The helium requirement decreases and the residual vapor weight increases with increasing pressurant temperature because of the increasing hydrogen partial pressure. The tank pressure effect is shown in Figure C-30. The vent pressure was not held constant for these runs because a NPSP of 5 psia was desired whenever possible. In runs 34 and 36, this was achieved by maintaining a 5 psia difference between the expulsion and vent pressures. However, in run 35, a difference of 3 psia was used, because venting to a lower pressure than the initial condition of 17 psia would result in an objectionable boiloff weight. The helium requirement increases with increasing tank pressure because of the increasing partial pressure requirement. Residual weight increases and boiloff decreases with increasing pressure because of the increase in hydrogen partial pressure and liquid temperature. The effect of insulation thickness is shown in Figure C-31. Boiloff weight shows a significant variation, while the helium and residual vapor weights are relatively constant. Increasing the vent pressure increases the residual vapor weight and decreases the helium weight because of the increase in hydrogen partial pressure. Boiloff weight decreases because of the increase in energy stored in the liquid. The boiloff increases as the ratio of tank-surface-area to tank-volume increases, while the residual and helium weights are essentially constant.

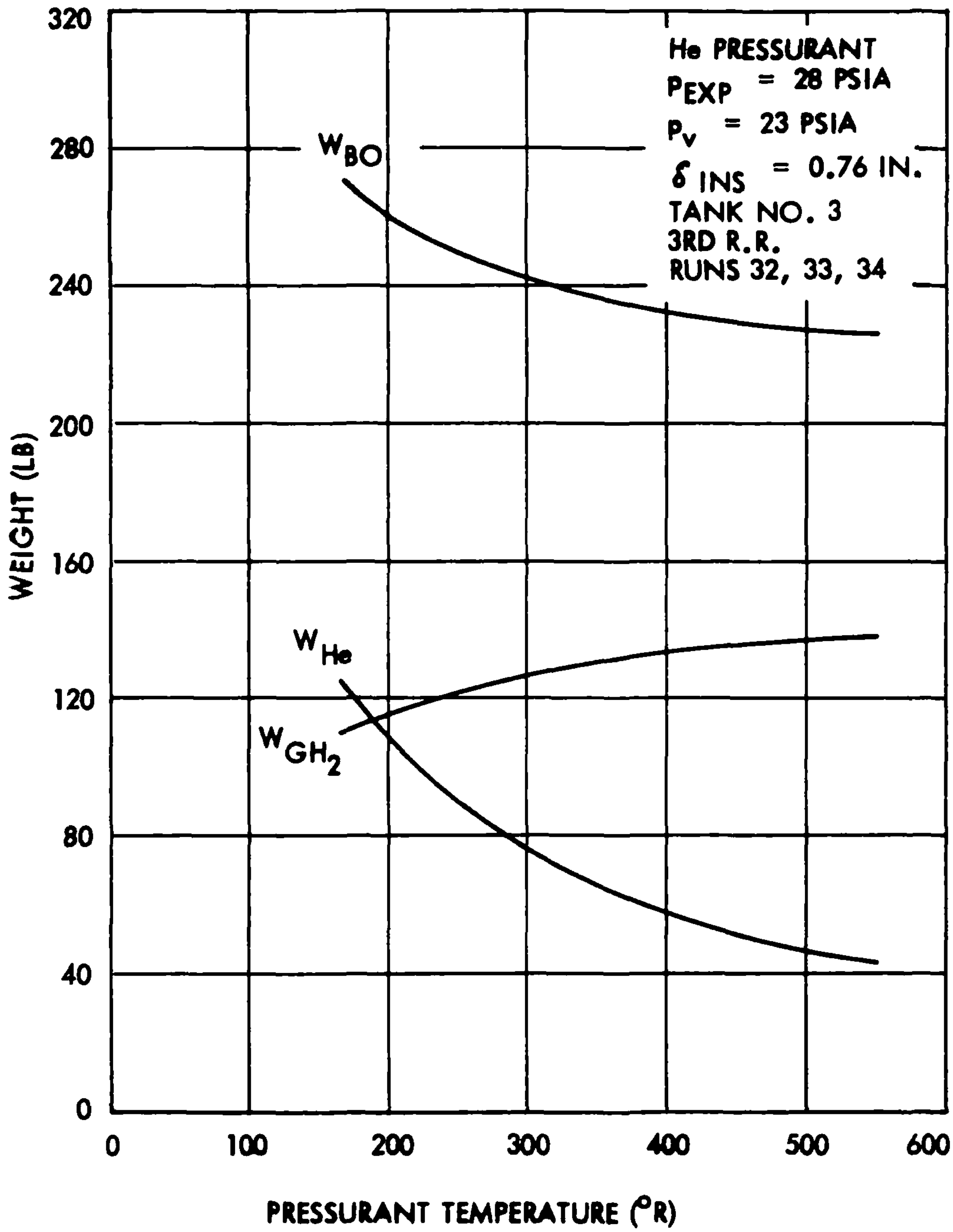


Fig. C-28 OMS LH_2 Tanks - Boiloff, He Pressurant and Hydrogen Residual Weights Vs Pressurant Temperature

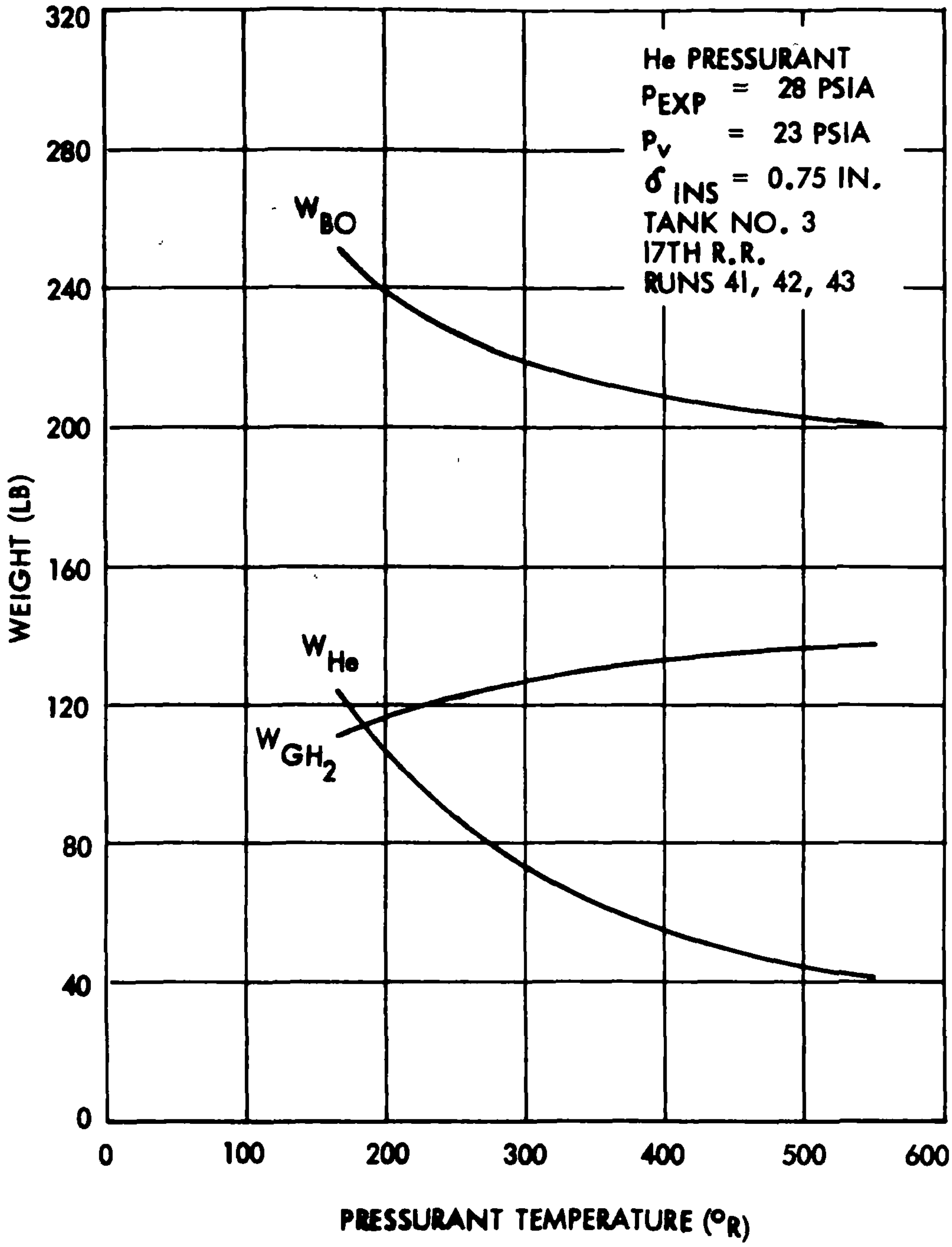


Fig. C-29 OMS LH_2 Tanks - Boiloff, He Pressurant and Hydrogen Residual Weights Vs Pressurant Temperature

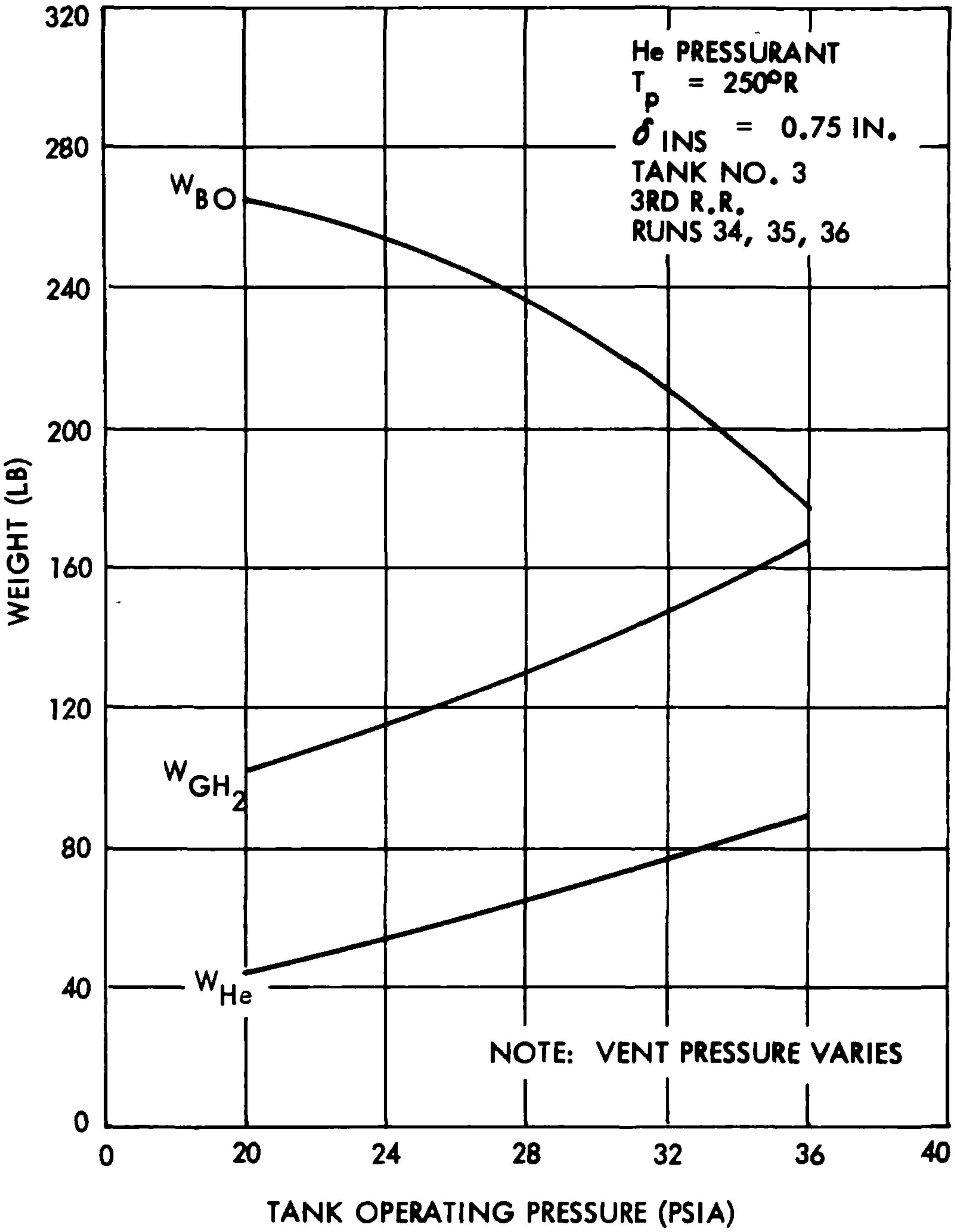


Fig. C-30 OMS LH_2 Tanks - Boiloff, He Pressurant and Hydrogen Residual Weights Vs Tank Operating Pressure

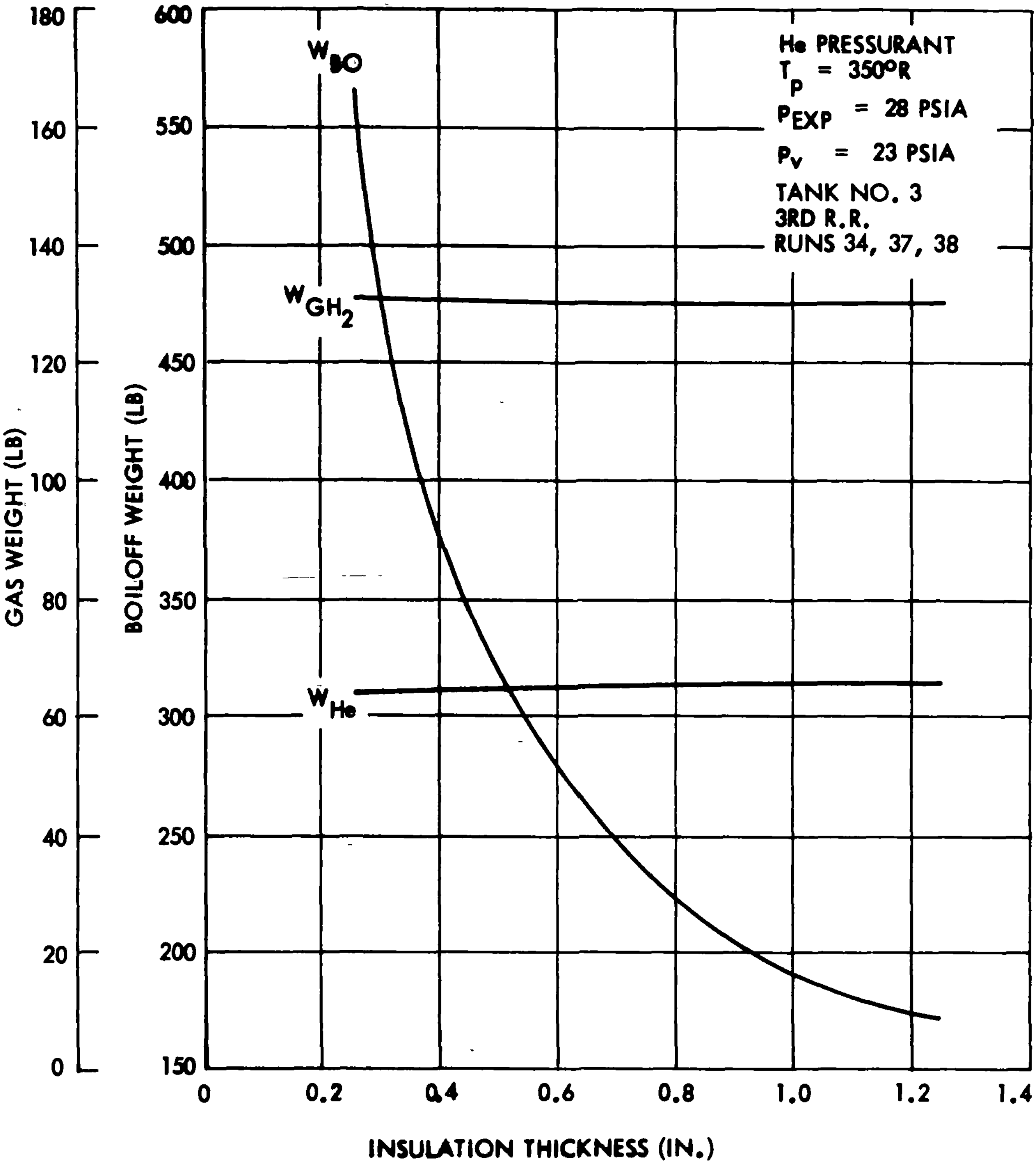


Fig. C-31 OMS LH_2 Tanks - Boiloff, He Pressurant and Hydrogen Residual Weights Vs Insulation Thickness

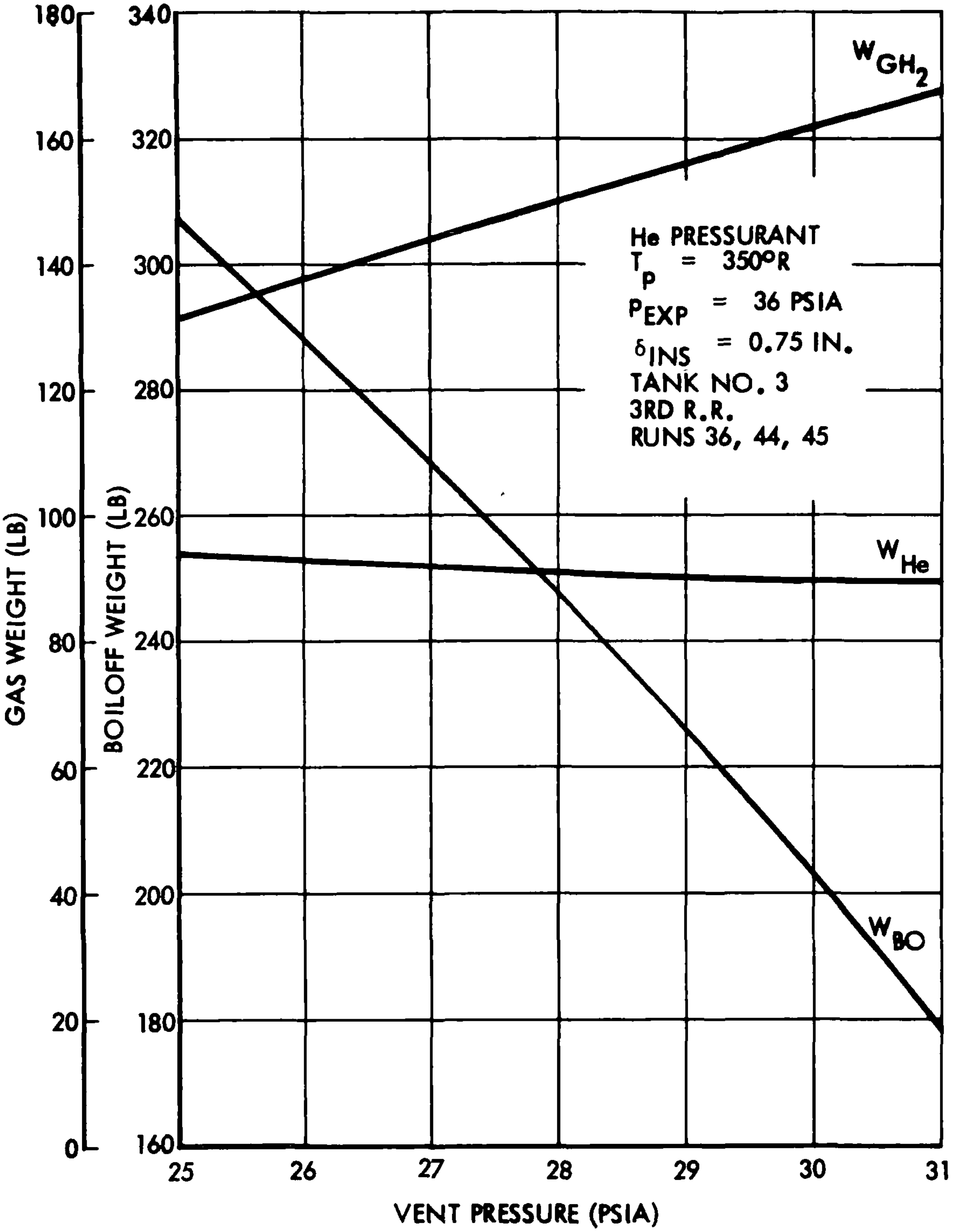


Fig. C-32 OMS LH_2 Tanks - Boiloff, He Pressurant and Hydrogen Residual Weights Vs Vent Pressure

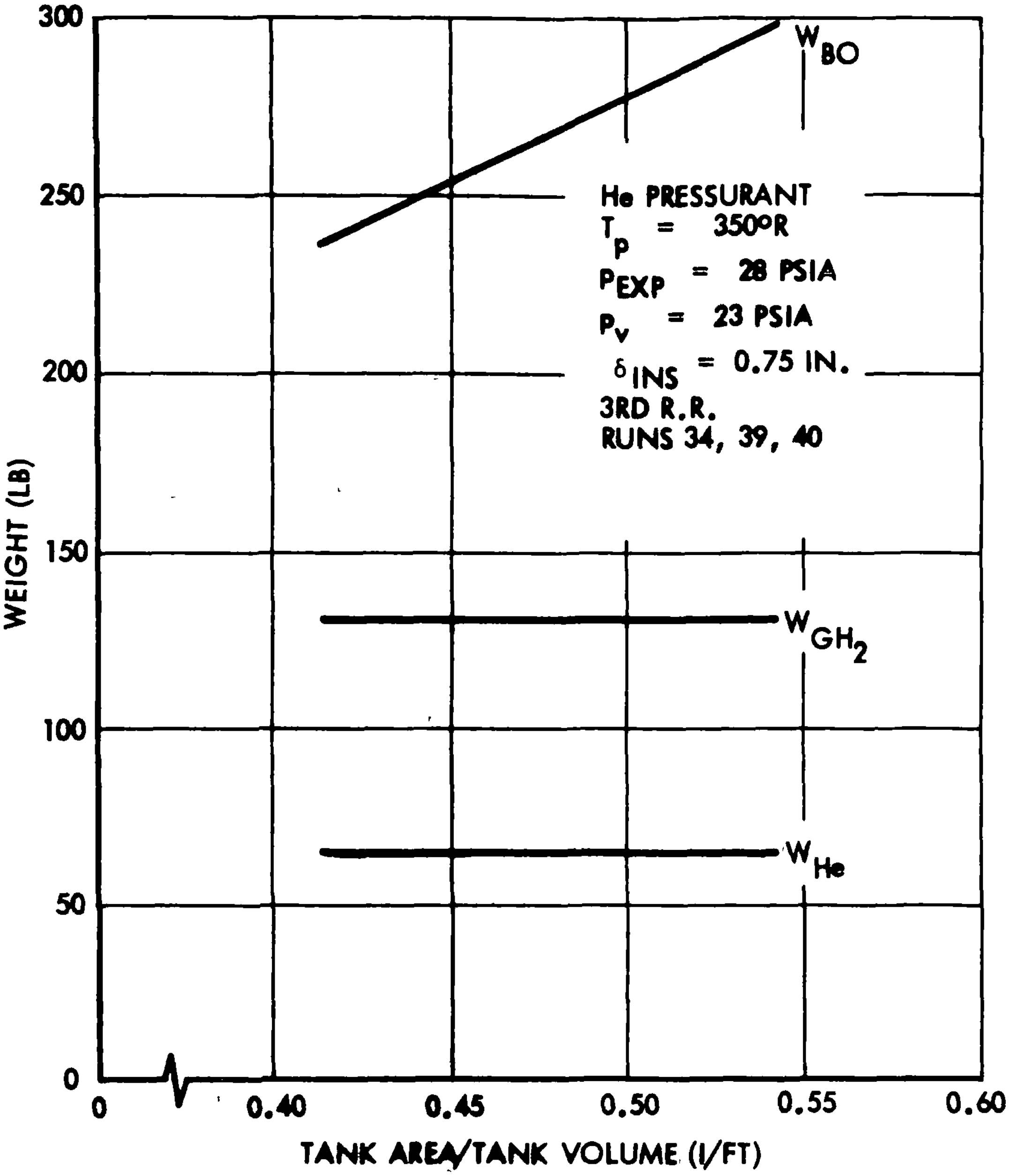


Fig. C-33 OMS LH_2 Tanks - Boiloff, He Pressurant and Hydrogen Residual Weights Vs Tank Geometry

Hydrogen Tanks - Hydrogen Vapor Pressurization

Results for hydrogen-vapor pressurization of the hydrogen tanks are shown in Figures C-34 through C-39. In these cases, the prepressurant weights are less than the expulsion pressurant weights. This is the reverse of the results for oxygen-vapor pressurization of the oxygen tanks. The enthalpy level of the hydrogen vapor is considerably greater than that of oxygen vapor at the same conditions of pressure and temperature. For instance, at a temperature of 540°R and pressure of 15 psia, the enthalpy of the hydrogen vapor is over seven times that of the oxygen vapor. This higher energy level results in a reduced mass requirement to achieve a given pressure rise. This is especially true in the case of hydrogen, since the initial mass of the ullage is relatively low because of the low density. The density of saturated hydrogen vapor at 15 psia is less than one third that of saturated oxygen vapor at 15 psia. As the pressurant energy level increases and the initial ullage mass decreases, the pressurant mass requirement decreases. In addition to this effect, the pressure increment for the hydrogen prepressurization is less, thus reducing the pressurant mass requirements.

The prepressurant, expulsion pressurant, residual vapor, and boiloff weights all decrease with increasing pressurant temperature for both the third and seventeenth revolution rendezvous missions as shown in Figures C-34 and C-35.

Assessing the effect of tank-operating pressure shown in Figure C-36, it should be remembered that the vent pressure was not held constant for the same reasons discussed in regard to Figure C-30. Figures C-37, C-38, and C-39 show variations similar to those for the corresponding helium pressurization cases.

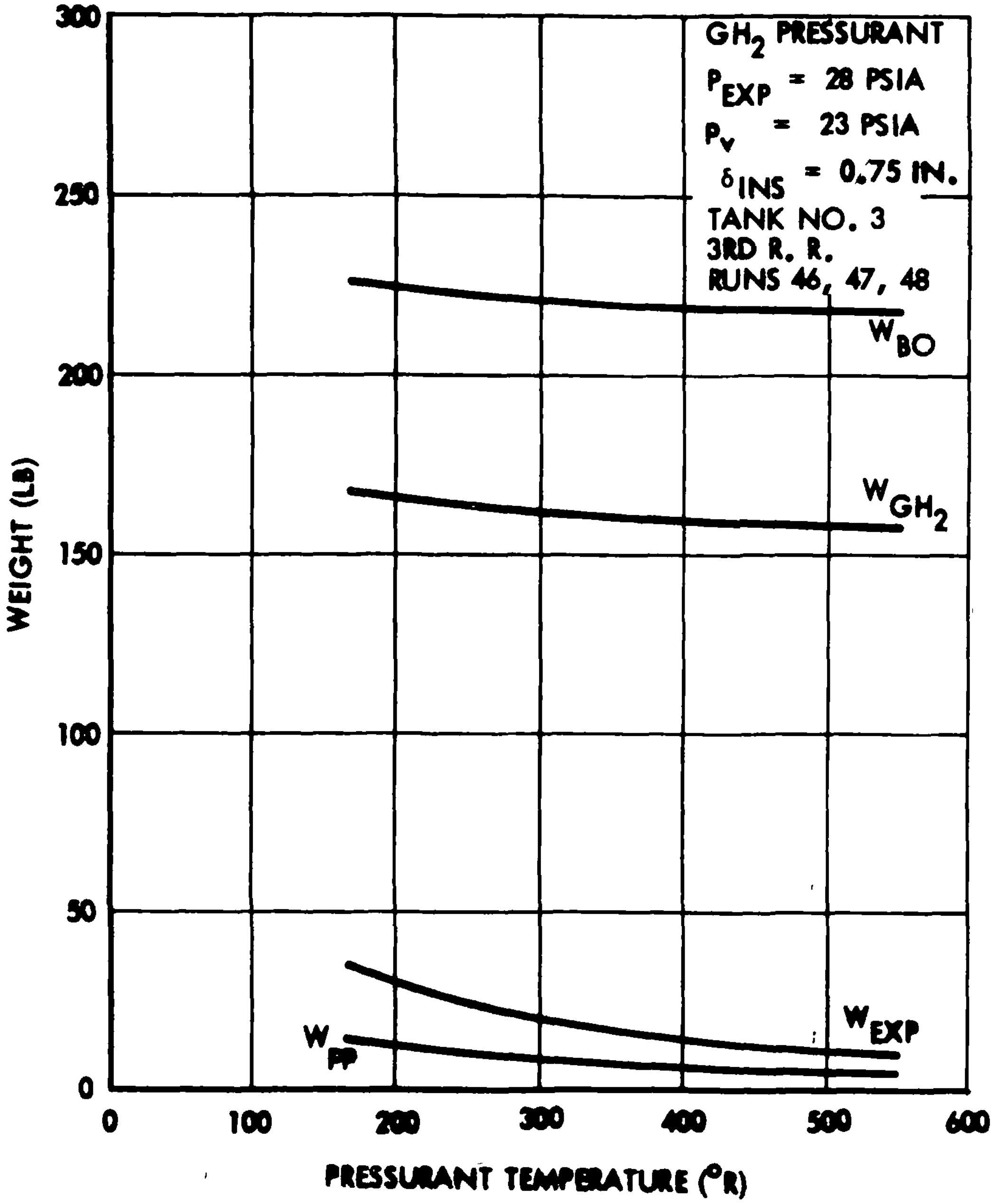


Fig. C-34 OMS LH_2 Tanks - Boiloff, GH_2 Pre-Pressurant, Pressurant and Residual Weights Vs Pressurant Temperature

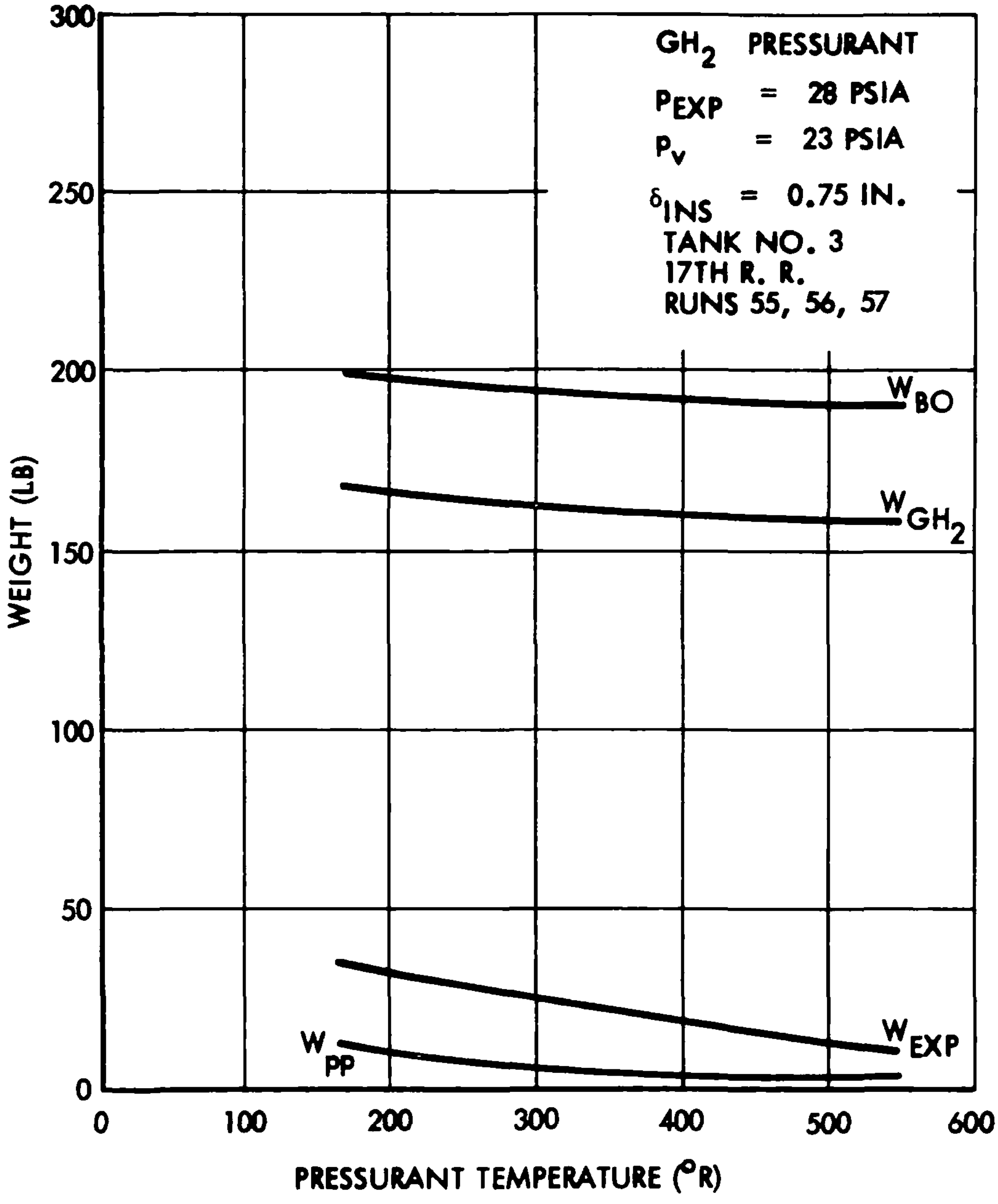


Fig. C-35 OMS LH_2 Tanks - Boiloff, GH_2 Pre-Pressurant, Pressurant and Residual Weights Vs Pressurant Temperature

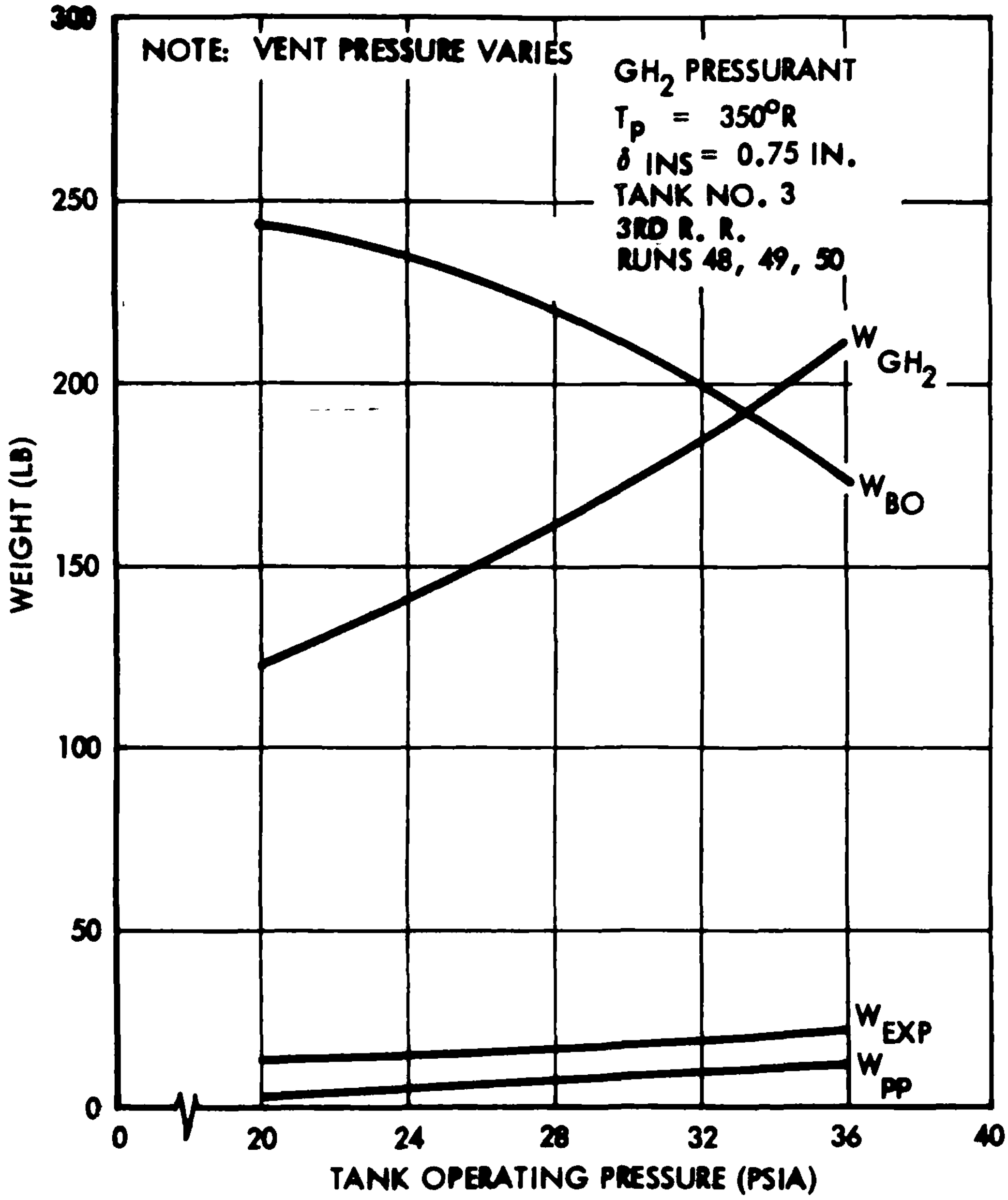


Fig. C-36 OMS LH_2 Tanks - Boiloff, GH_2 Pre-Pressurant, Pressurant and Residual Weights Vs Tank Operating Pressure

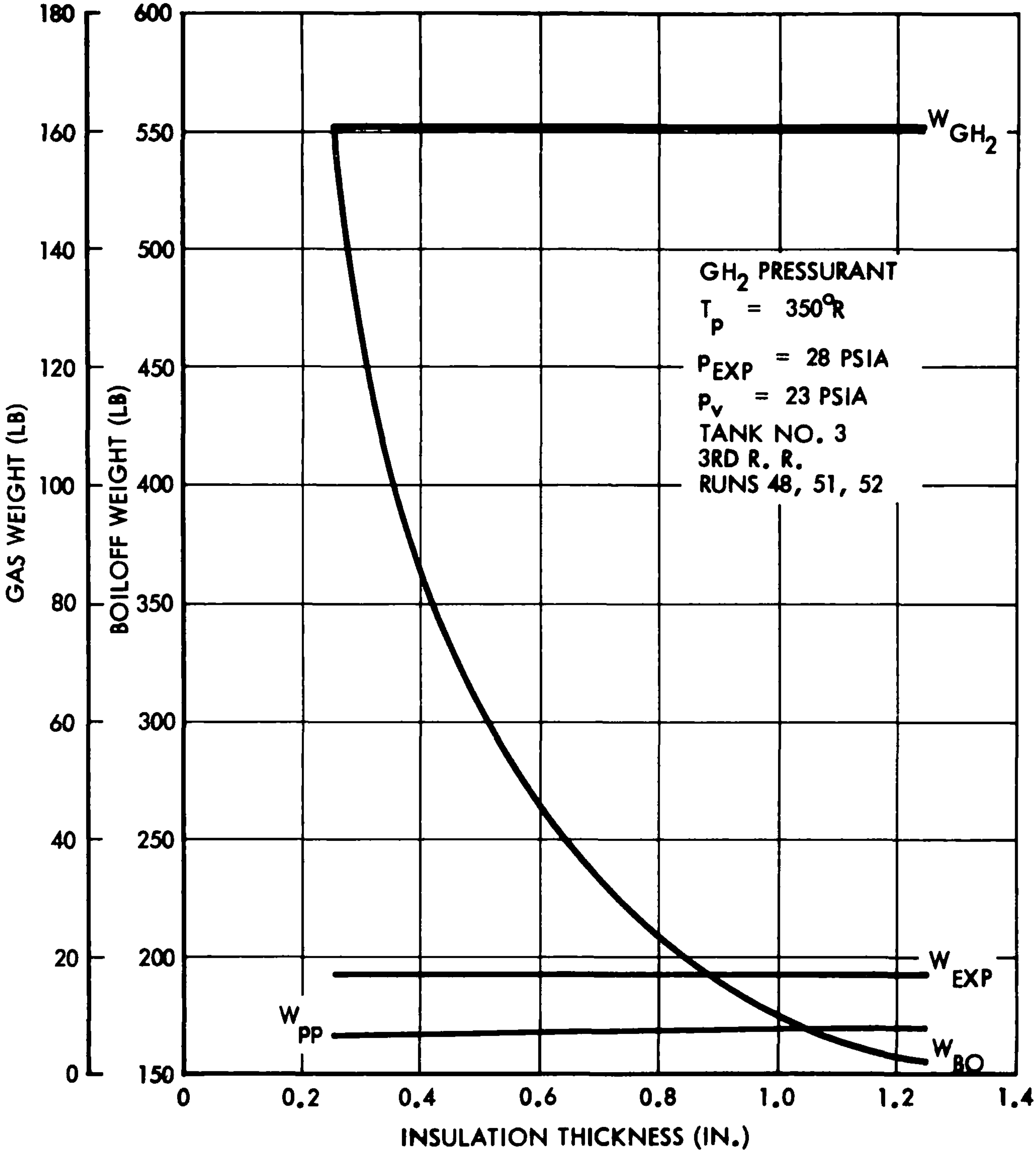


Fig. C-37 OMS LH_2 Tanks - Boiloff, GH_2 Pre-Pressurant, Pressurant and Residual Weights Vs Insulation Thickness

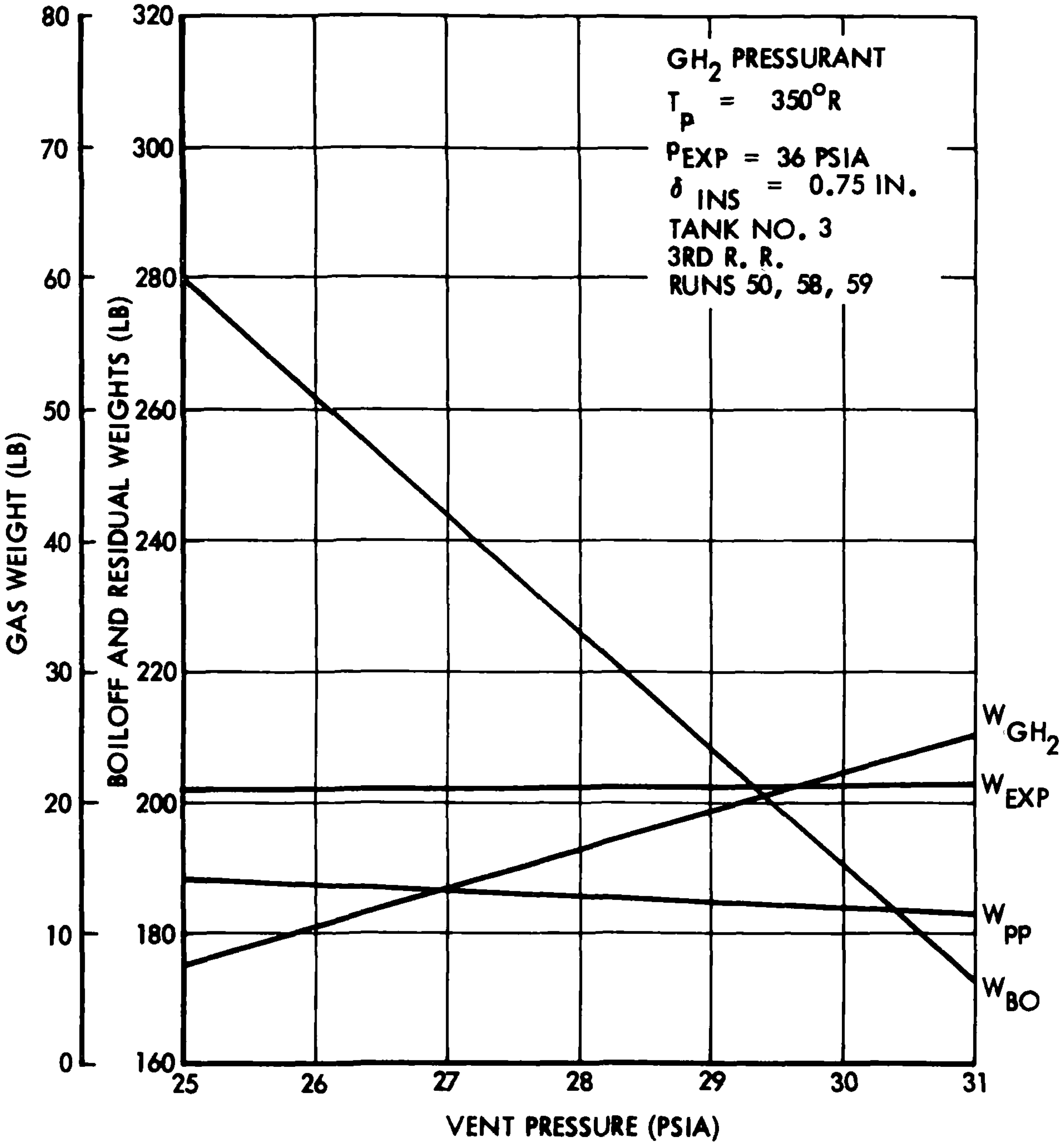


Fig. C-38 OMS LH_2 Tanks - Boiloff, GH_2 Pre-Pressurant, Pressurant and Residual Weights Vs Vent Pressure

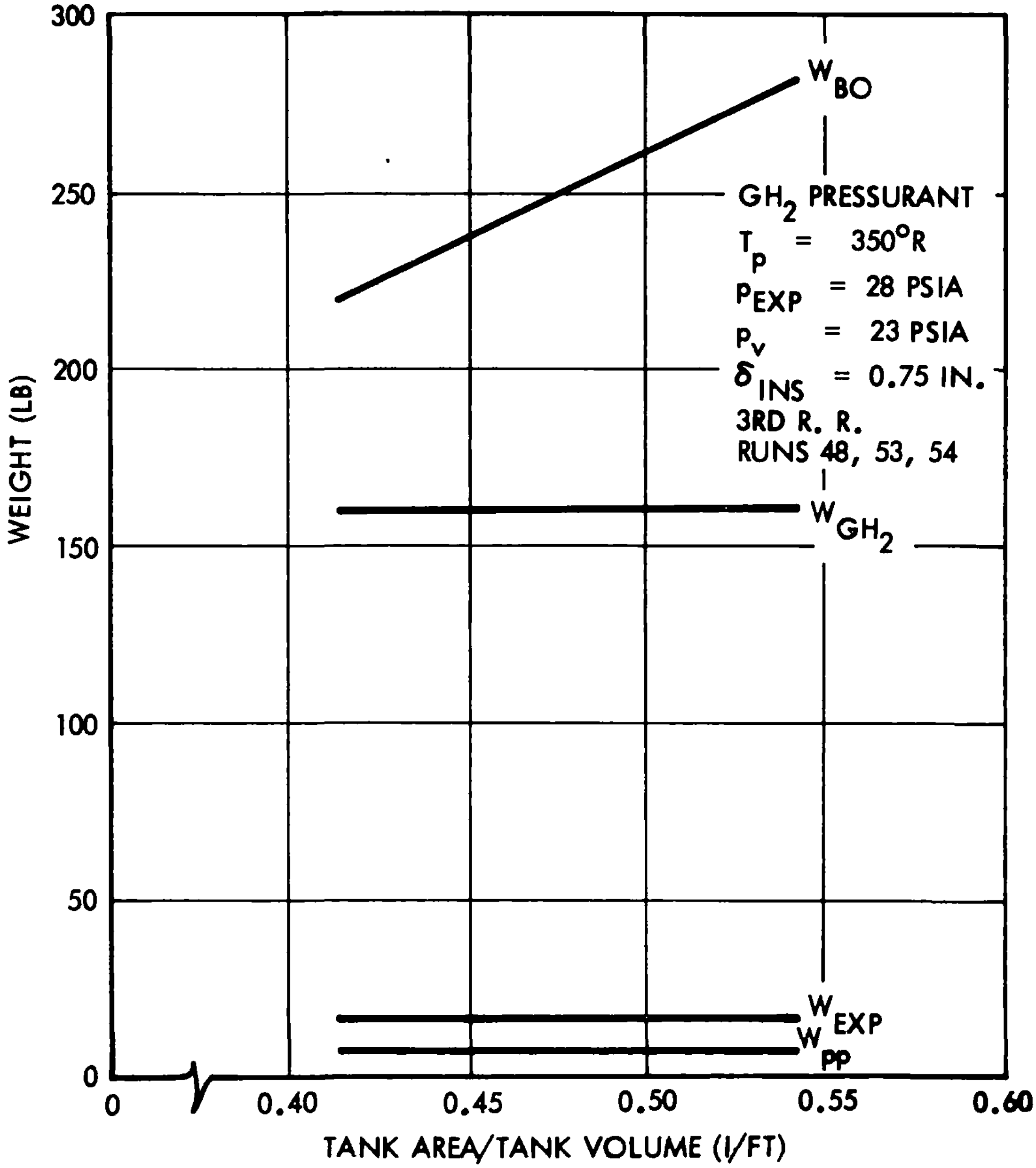


Fig. C-39 OMS LH_2 Tanks - Boiloff, GH_2 Pre-Pressurant, Pressurant and Residual Weights Vs Tank Geometry

C.2.2 Orbit Injection Propellant Supply Pressurization Analysis (Modulated Flow)

The Orbit Injection Propellant Supply Pressurization Analyses were performed in detail for the modulated flow method of control. The results were employed in determining several sensitivities. The Orbit Injection tank geometry used in these analyses is shown in Figure C-40. Tank wall thermal properties were assumed to be those of 2219 aluminum. Wall thicknesses for these tanks are listed in Table C-12.

Table C-12

ORBIT INJECTION TANK WALL THICKNESS DATA

Location	$t_{Membrane}$ (in.)	$\bar{t}_{Rings+Stringers}$ (in.)	$\bar{t}_{Total}$ (in.)
Fwd Dome LOX Tank	0.025	-	0.025
Fwd Cone LOX Tank	0.025	0.073	0.098
Aft Cone LOX Tank	0.090	0.008	0.098
Common Bulkhead*	0.025	0.098	0.123
Fwd Cyl. LH_2 Tank	0.056	0.069	0.125
Aft Cyl. LH_2 Tank	0.043	0.082	0.125
Aft Dome LH_2 Tank	0.025	-	0.025

* Common bulkhead covered with Fibreglas honeycomb, one-in. thick, $k = 0.033$ Btu/hr ft^{o}R

Propellant heating, pressurization, and stratification computations were performed using the Asymmetric Propellant Heating Code (APHC). This program computes a numerical solution to equations describing the pressurization, liquid-ullage coupling, and thermal stratification processes as a function of time in a propellant tank experiencing a time-varying acceleration and sidewall heat flux. Input data for ascent acceleration and flowrate are shown in Figures C-41 and C-42. Fixed input data and initial conditions are presented in Table C-13. Variable input data for each tank included values

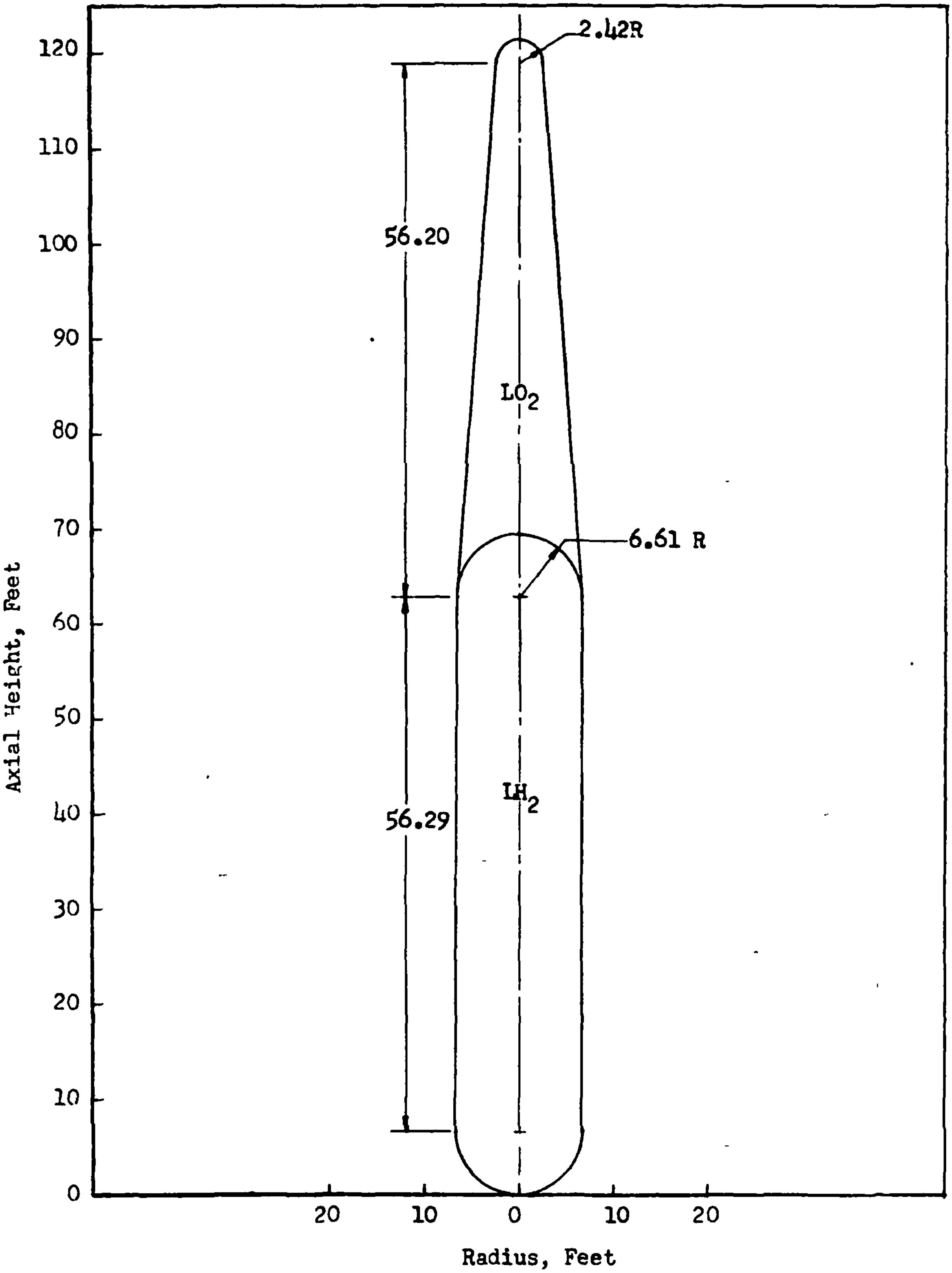


Fig. C-40 Ascent Tank Configuration for Pressurization Analyses

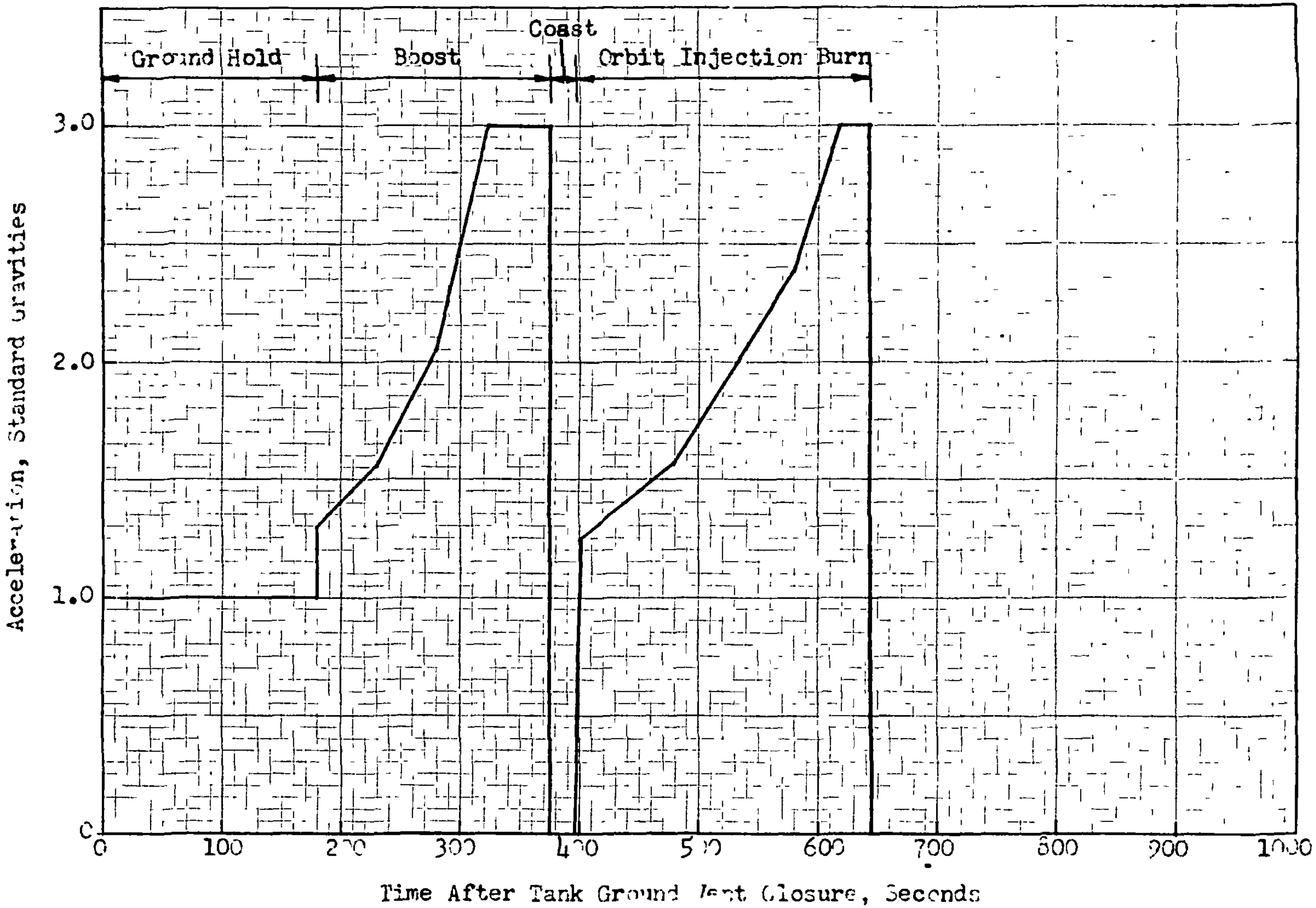


Fig. C-41 Acceleration Input Data for Pressurization Calculations

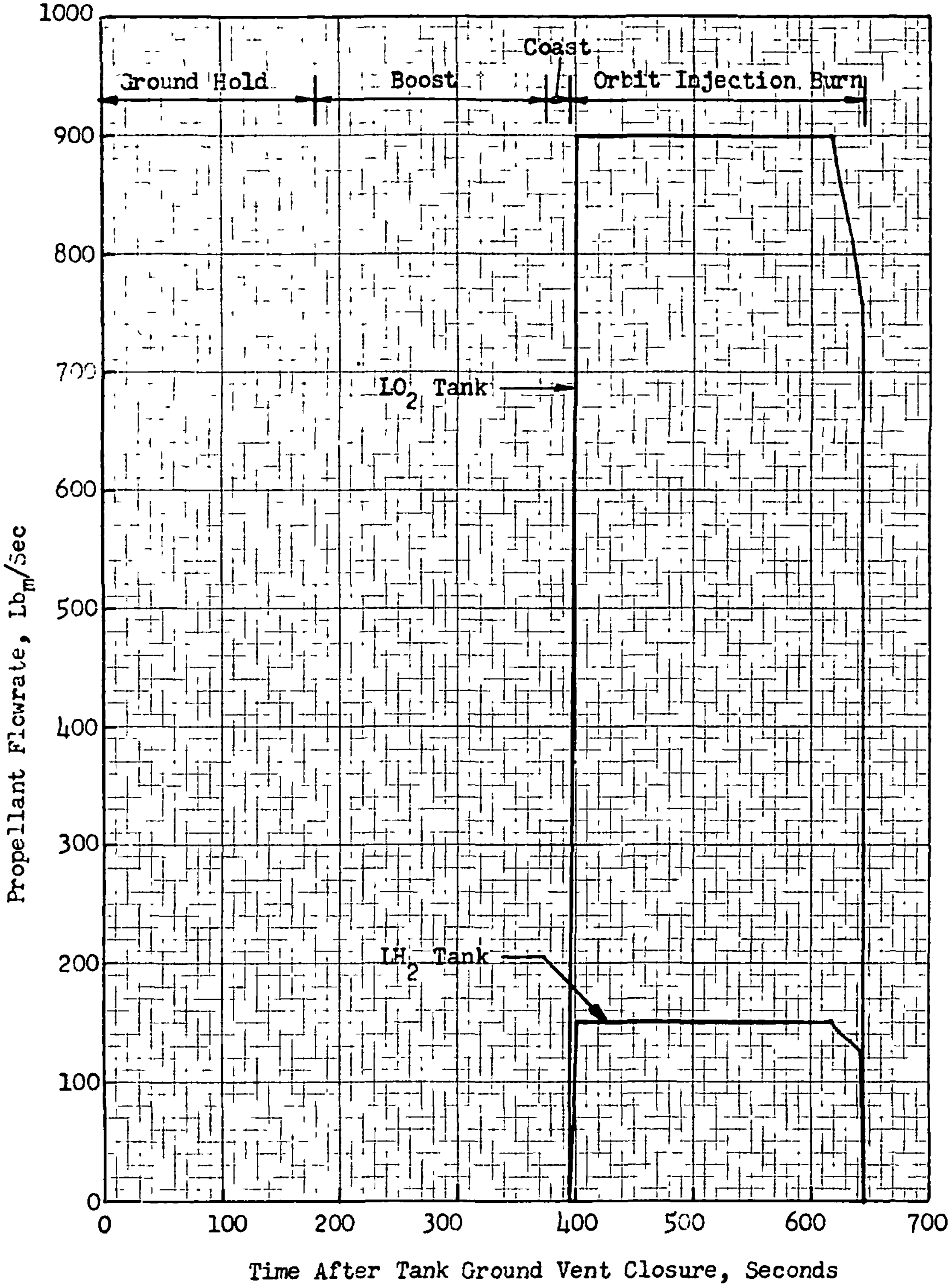


Fig. C-42 Flowrate Input Data for Pressurization Calculations

Table C-13

FIXED INPUT DATA FOR PRESSURIZATION ANALYSES

Item	LO_2 Tank	LH_2 Tank
Propellant Loading, lb_m	220,500	37,000
Total Tank Volume, ft^3	3,239	8,926
Initial Ullage Volume, ft^3	122	532 (1)
Total Surface Area, ft^2	1,523	2,855
Initial Propellant Saturation Pressure (2), psia	17.00	17.00
Operating Pressure, psia	25.00	30.00
Ground Hold Duration, sec	180	180

Notes: (1) Initial ullage includes vapor trapped during loading operation.

(2) Saturation condition is at start of ground hold period.

of external insulation thickness, engine feedline length, and pressurant gas inlet temperature. An engine bleed pressurization system was assumed. A run log, showing the range of values assumed for the pertinent independent variables, is shown in Table C-14. In all cases, the insulation was assumed to be polyurethane foam having a conductivity ranging from 010026 Btu/hr ft$^{\circ}$R at 37°R to 0.22 Btu/hr ft$^{\circ}$R at 600°R. The variation in thickness provided equivalent data to varying conductivity.

The results of the APHC runs, in terms of the parameter variations previously described, are presented in Figures C-43 through C-55. Sample variations of liquid-propellant temperature throughout the ascent duration are shown in Figure C-43 for the LO_2 tank with no insulation and in Figure C-44 for LH_2 with 0.05-in. insulation. These results illustrate the high degree of temperature stratification resulting from the high sidewall heat fluxes for this case. Corresponding values of cumulative pressurant gas mass, evaporated liquid mass and ullage vapor and ullage-wall temperature are

Table C-14

RUN LOG FOR ASCENT TANK PRESSURIZATION COMPUTATIONS

Run No.	Propellant	Feedline Length (ft)	Insulation Thickness (in)	Insulation Hot Boundary Temperature (°R)	Pressurant Gas Inlet Temperature (°R)
1	LO_2	30	0	530	300
2			0		500
3			0		800
4			0.5	500	300
5			0.5		500
6			0.5		800
7			1.0	300	300
8			1.0		500
9			1.0		800
10		100	0	530	300
11			0		500
12			0		800
13			0.5	500	300
14			0.5		500
15			0.5		800
16			1.0	300	300
17			1.0		500
18			1.0		800
19	LH_2	20	0.5	500	300
20			0.5		500
21			0.5		800
22			1.25		300
23			1.25		500
24			1.25		800
25			2.0	300	300
26			2.0		500
27			2.0		800
28		90	0.5	500	300
29			0.5		500
30			0.5		800
31			1.25		300
32			1.25		500
33			1.25		800
34			2.0	300	300
35			2.0		500
36			2.0		800
37	LO_2		0	530	300
38			0		500
39			0.5		500
40			1.0		500
41	LH_2		1.25	500	300
42			1.25		500
43			2.00		300
44			2.00		500

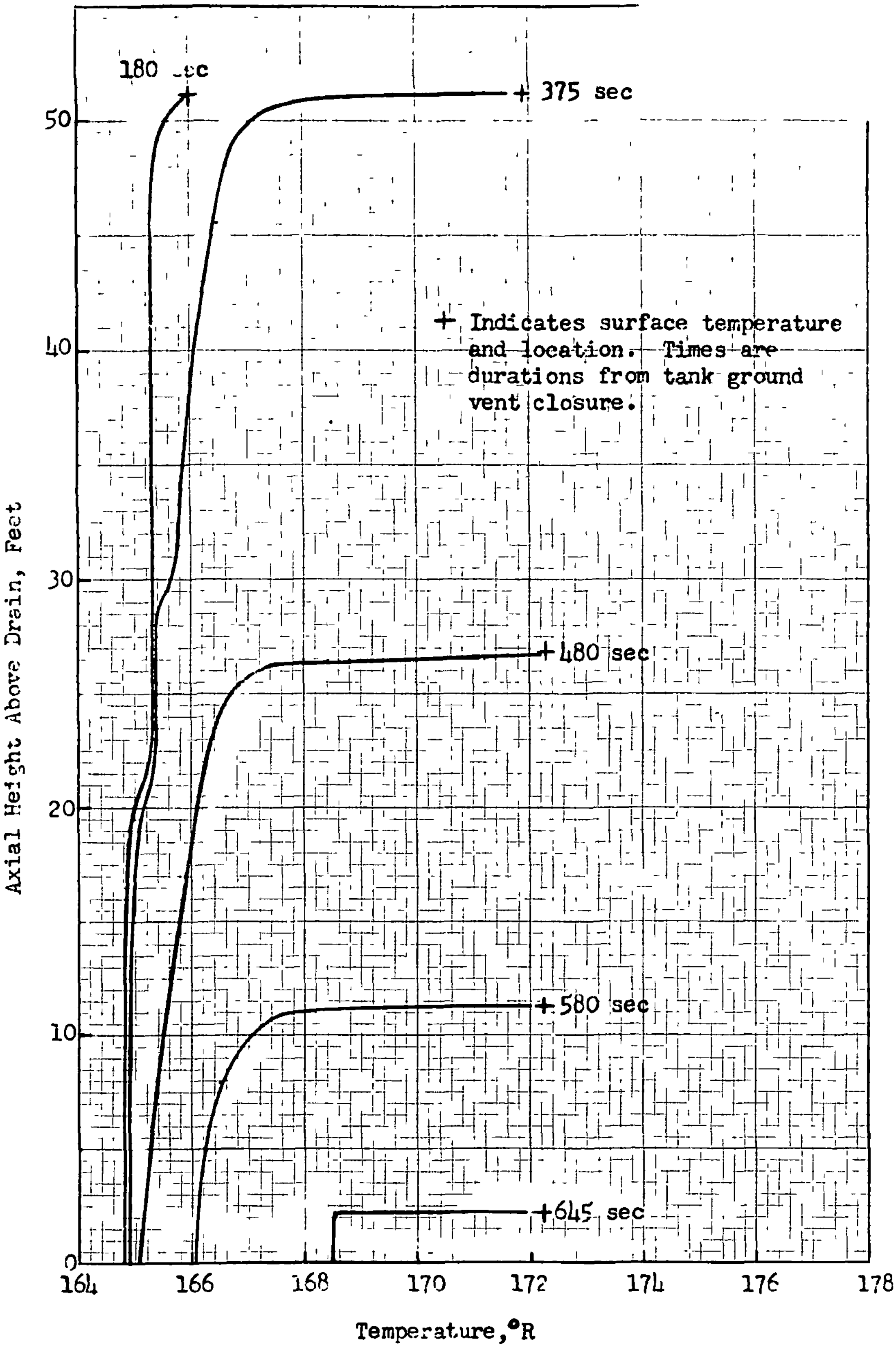


Fig. C-43 Liquid Temperature Profiles for LOX Ascent Tank - Run 2

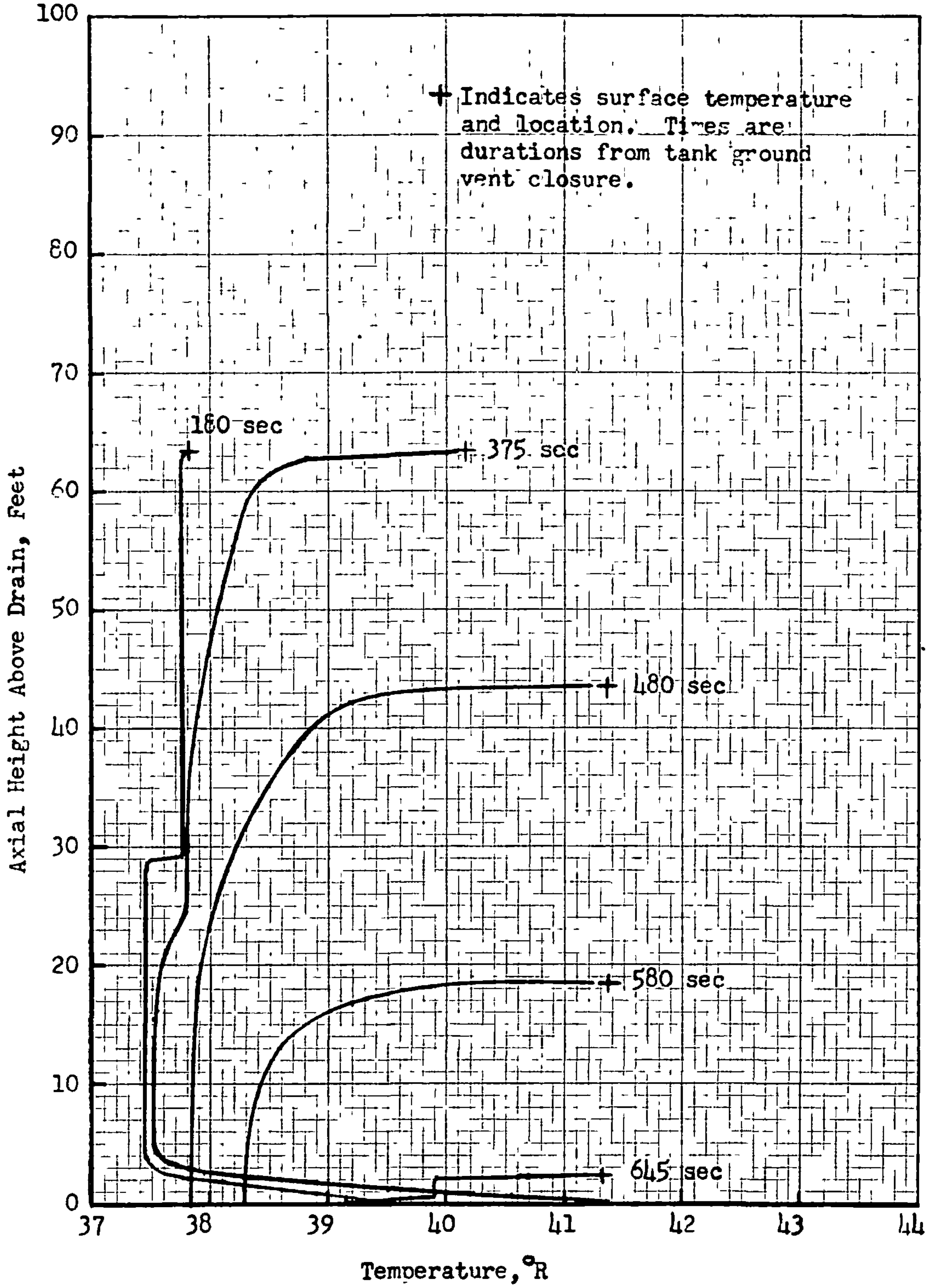


Fig. C-44 Liquid Temperature Profiles for LH_2 Ascent Tank - Run 20

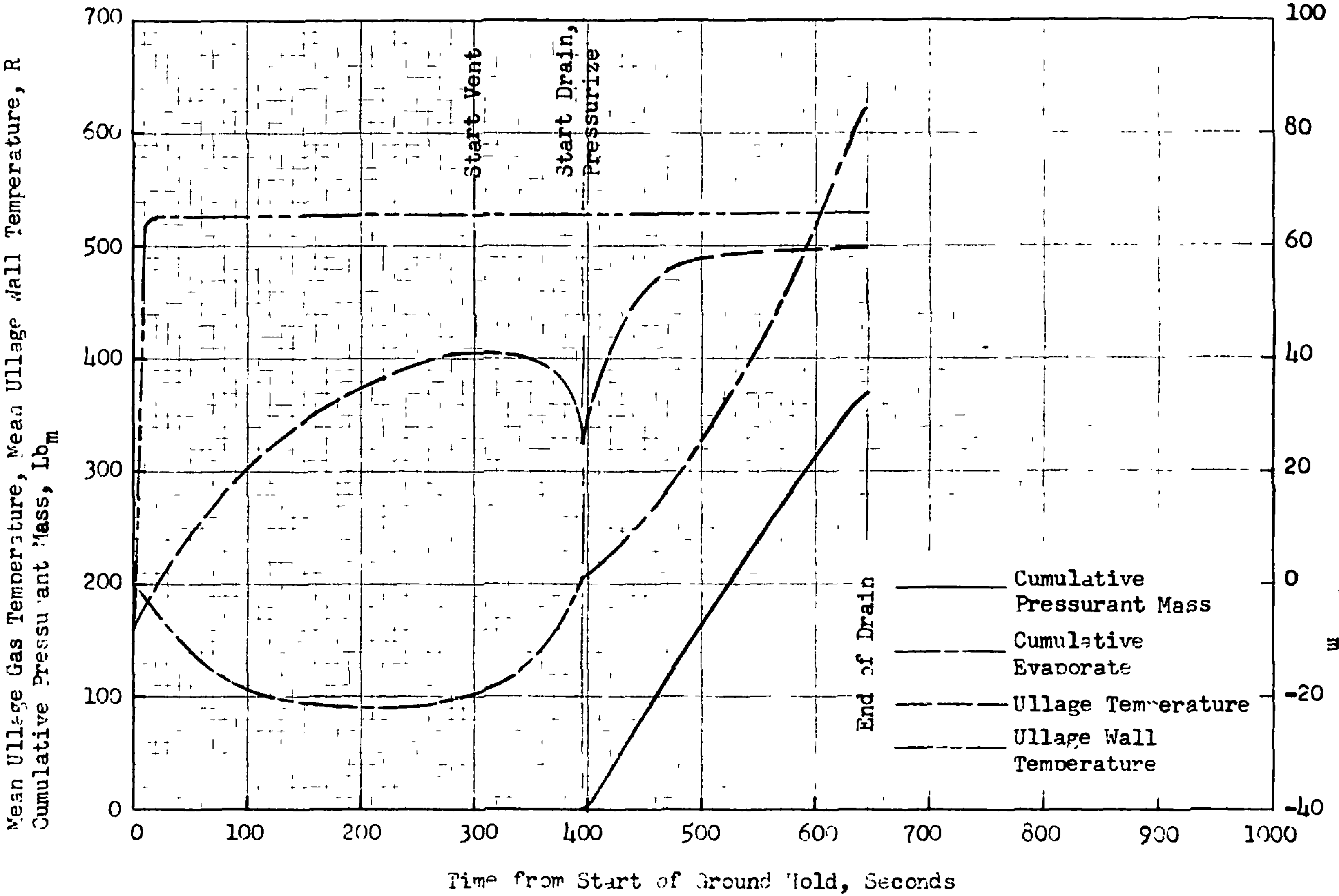


Fig. C-45 Cumulative Pressurant Gas and Evaporate Mass, Mean Ullage Gas and Ullage Wall Temperatures Vs Time for LOX Ascent Tank - Run 2

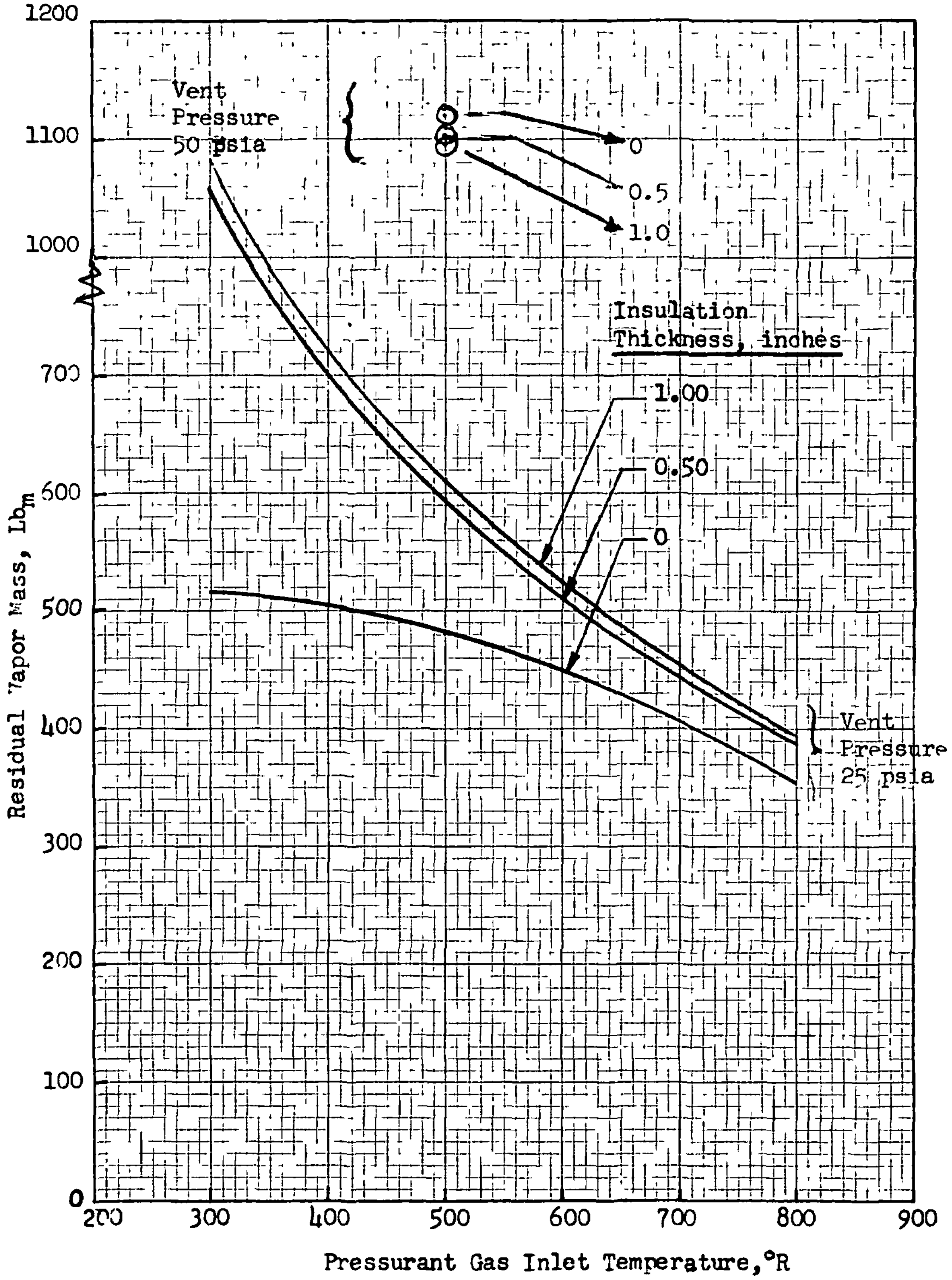


Fig. C-46 Residual Vapor Mass - Oxygen Ascent Tank

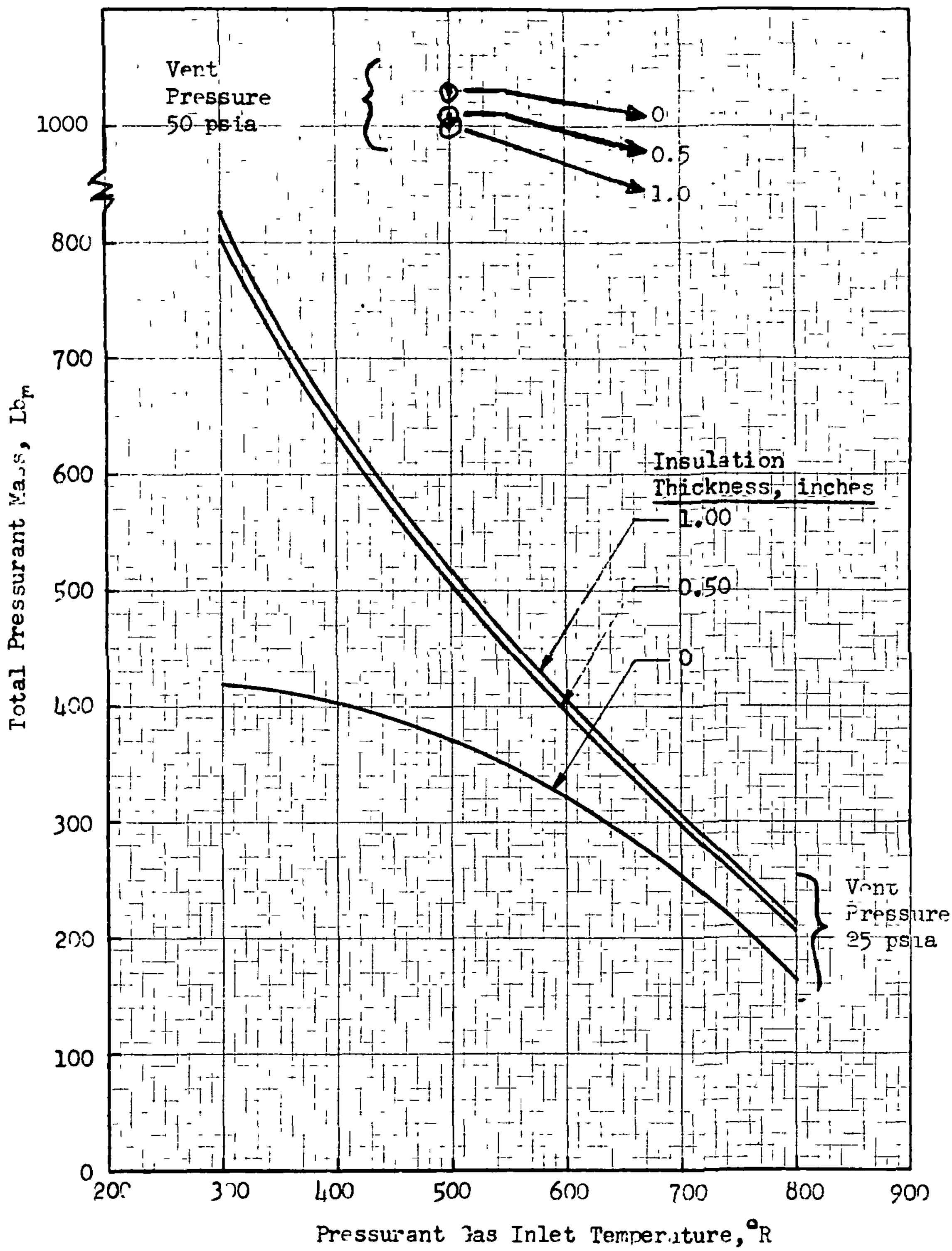


Fig. C-47 Pressurant Mass Requirements - Oxygen Ascent Tank

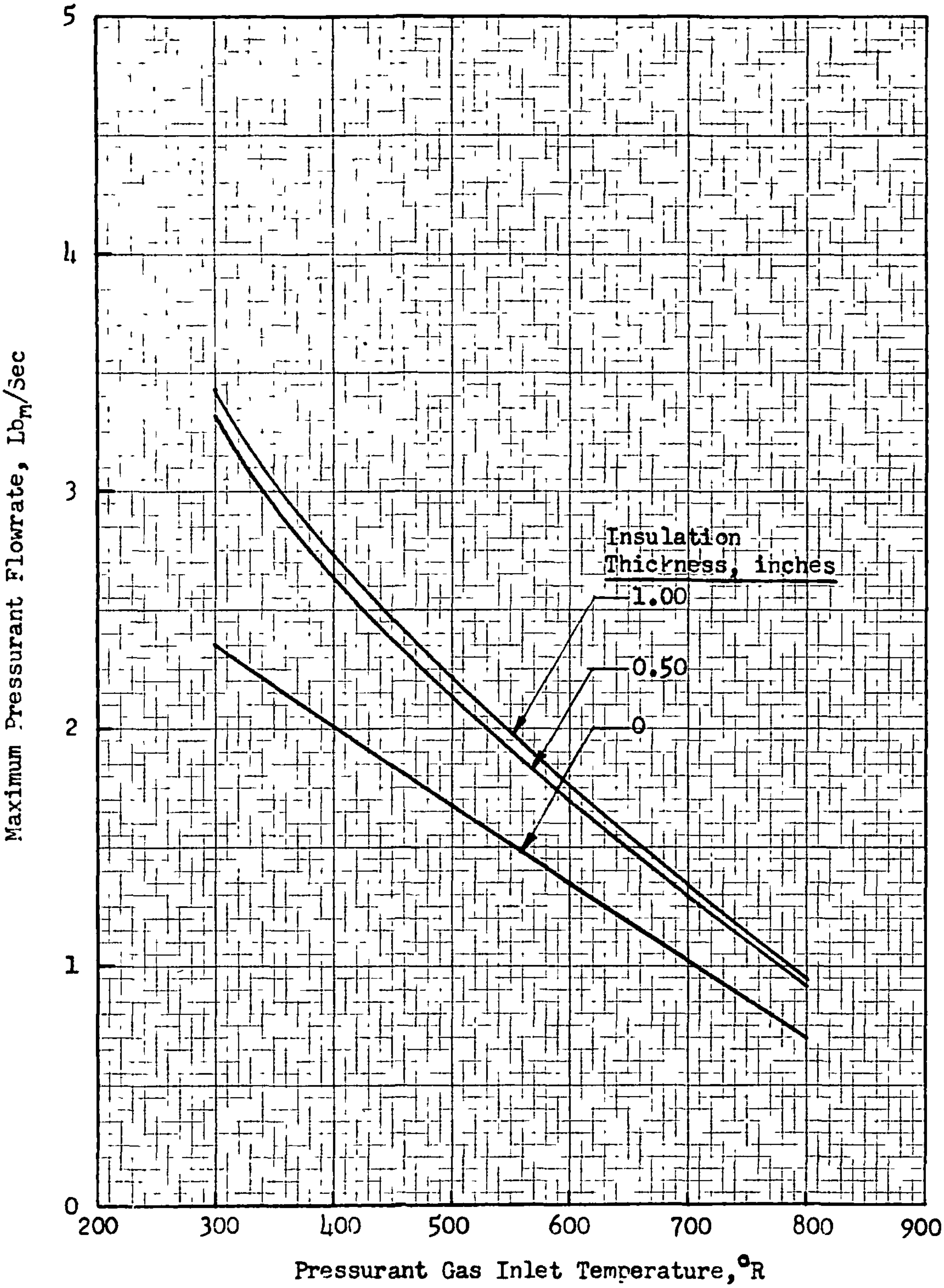


Fig. C-48 Maximum Pressurant Gas Flowrate - Oxygen Ascent Tank

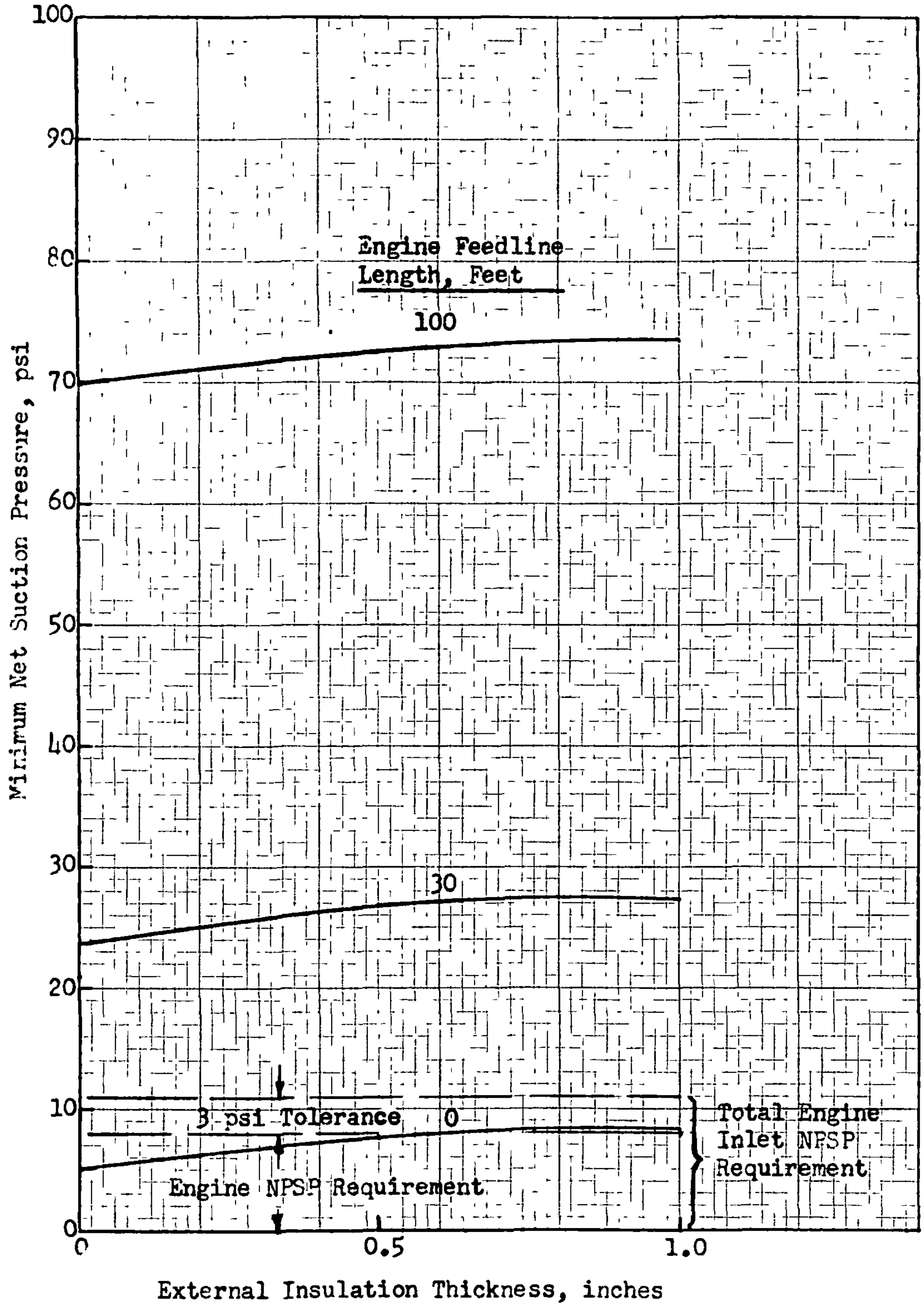


Fig. C-49 Engine Inlet Net Suction Pressure - Oxygen Ascent Tank

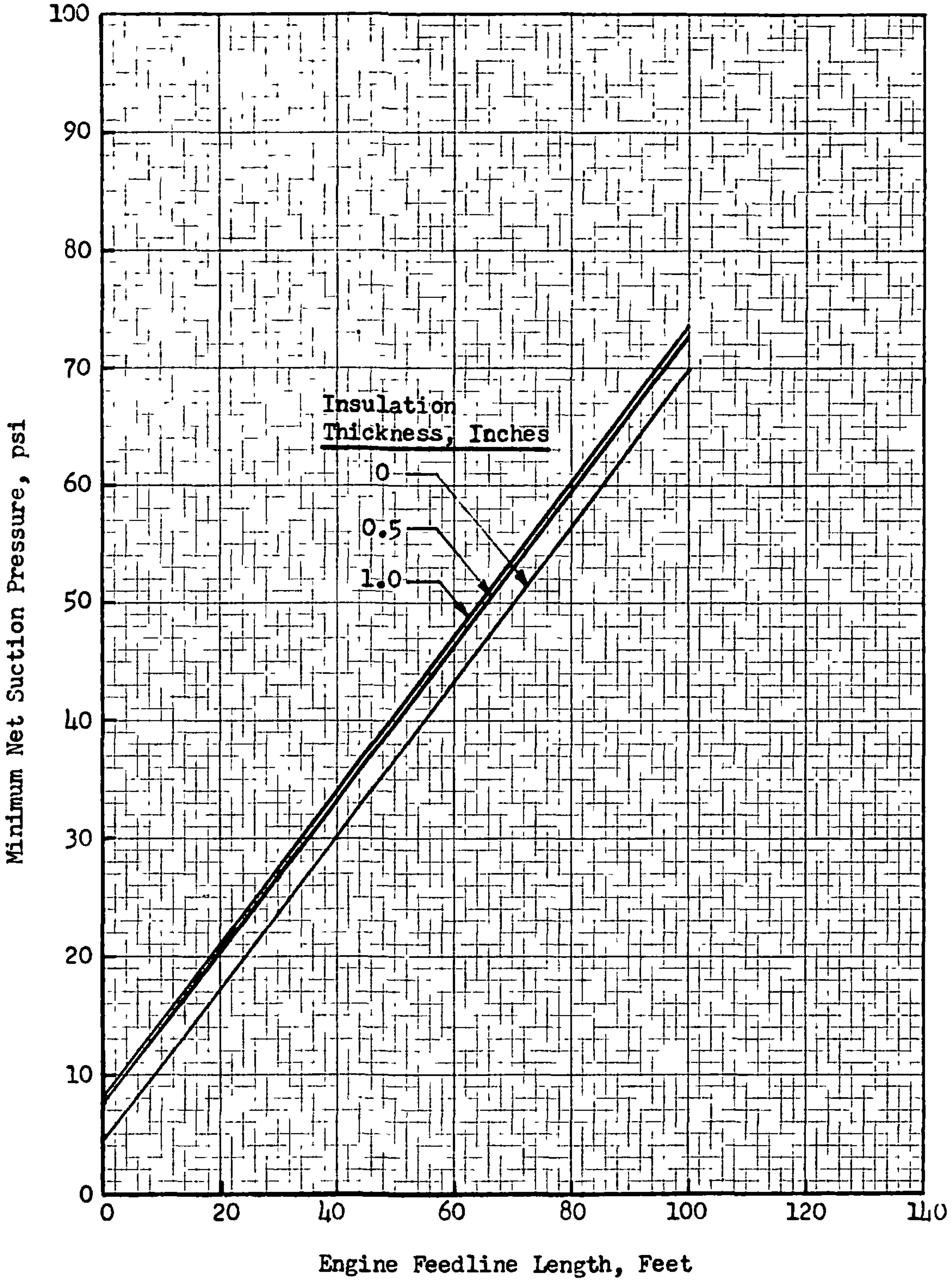


Fig. C-50 Engine Inlet Net Suction Pressure - Oxygen Ascent Tank

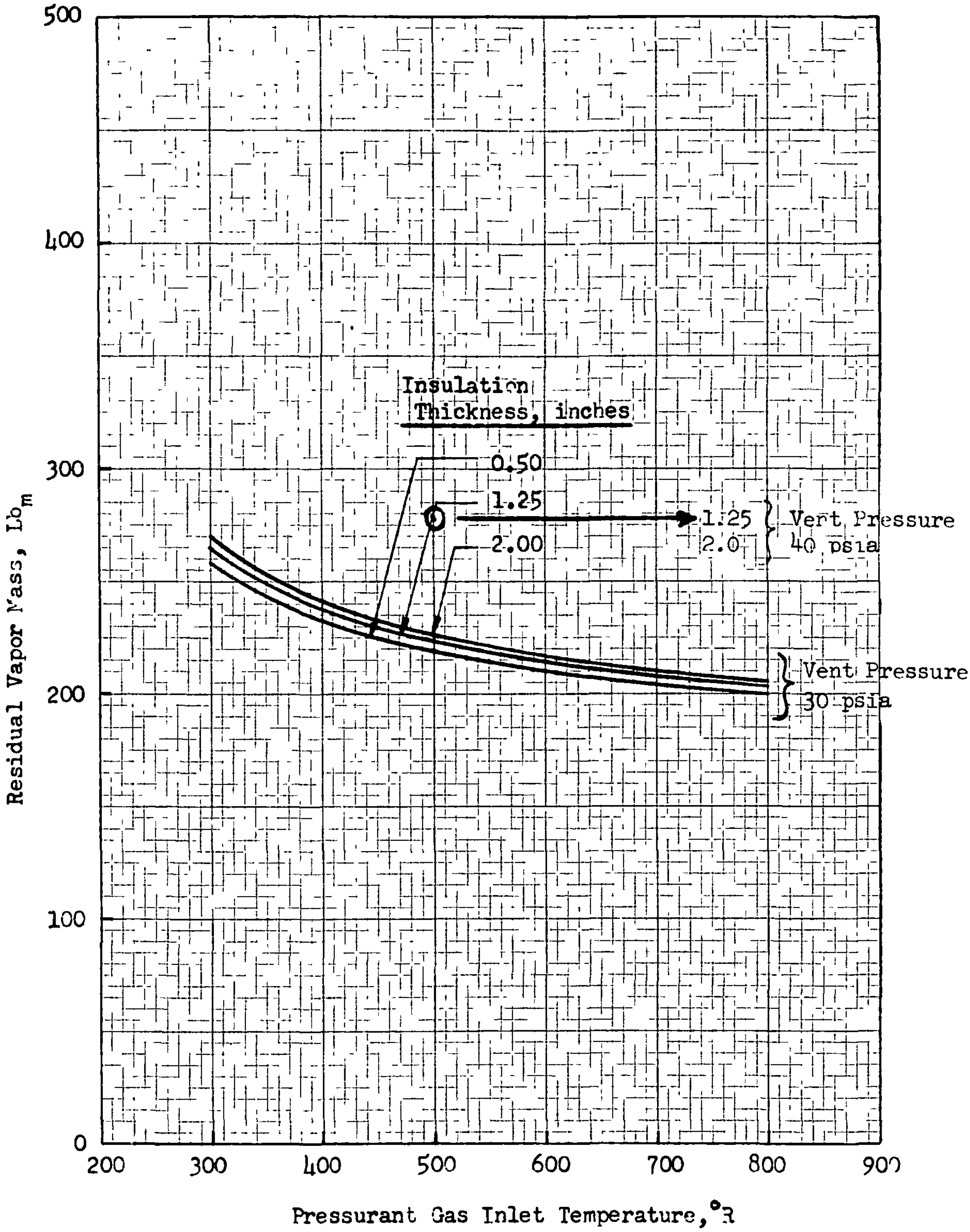


Fig. C-51 Residual Vapor Mass - Hydrogen Ascent Tank

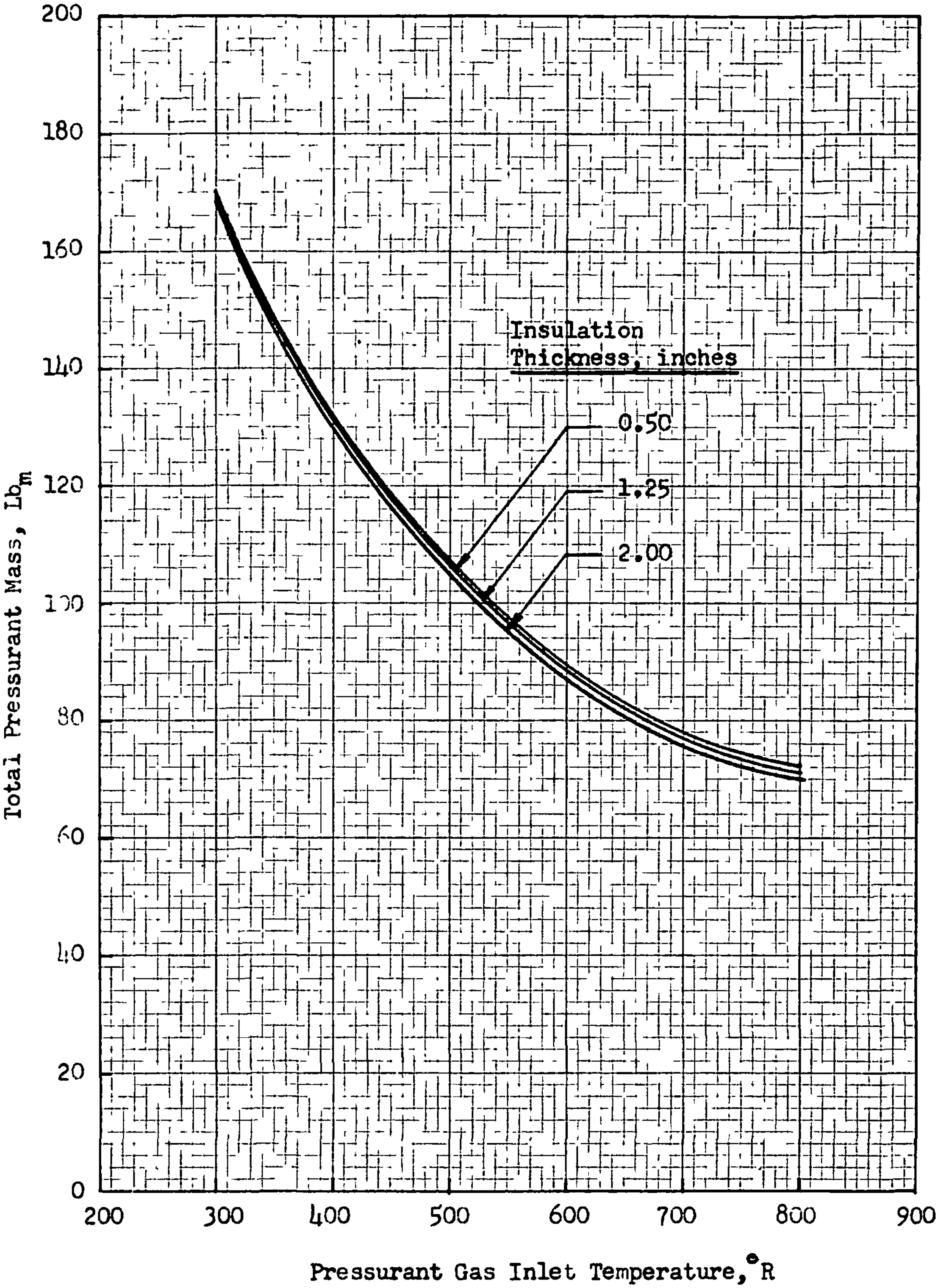


Fig. C-52 Pressurant Mass Requirements - Hydrogen Ascent Tank

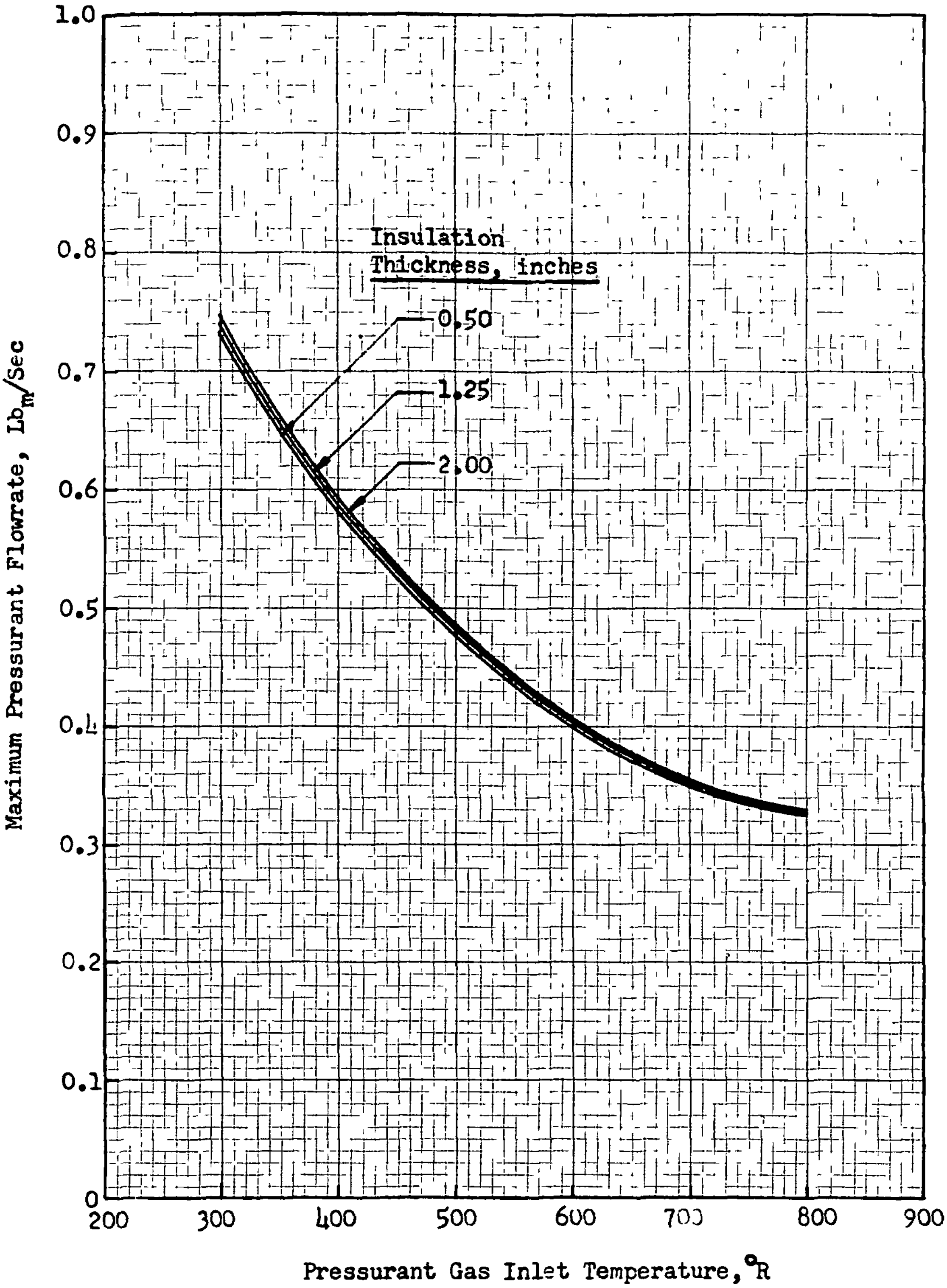


Fig. C-53 Maximum Pressurant Gas Flowrate - Hydrogen Ascent Tank

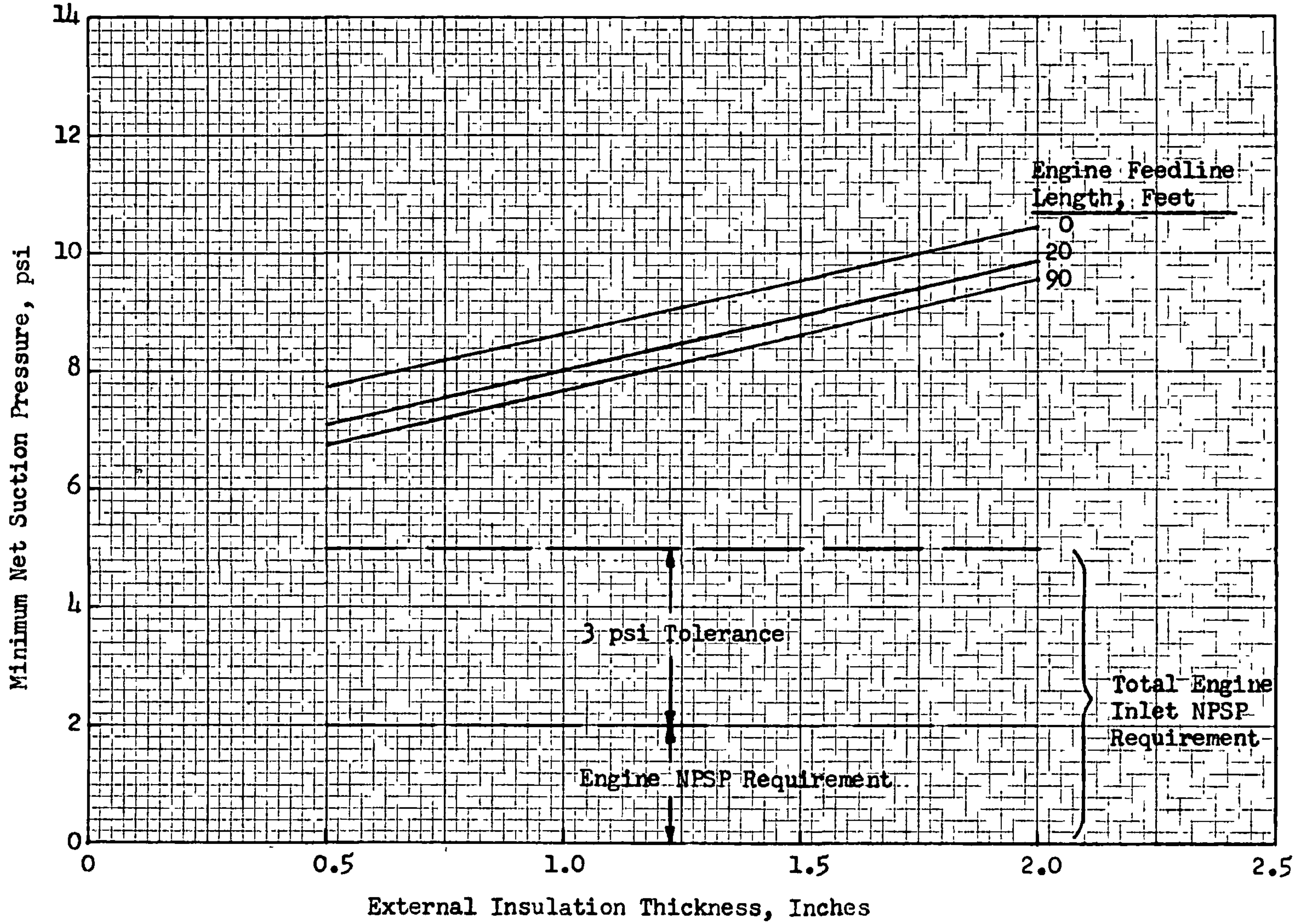


Fig. C-54 Engine Inlet Net Suction Pressure - Hydrogen Ascent Tank

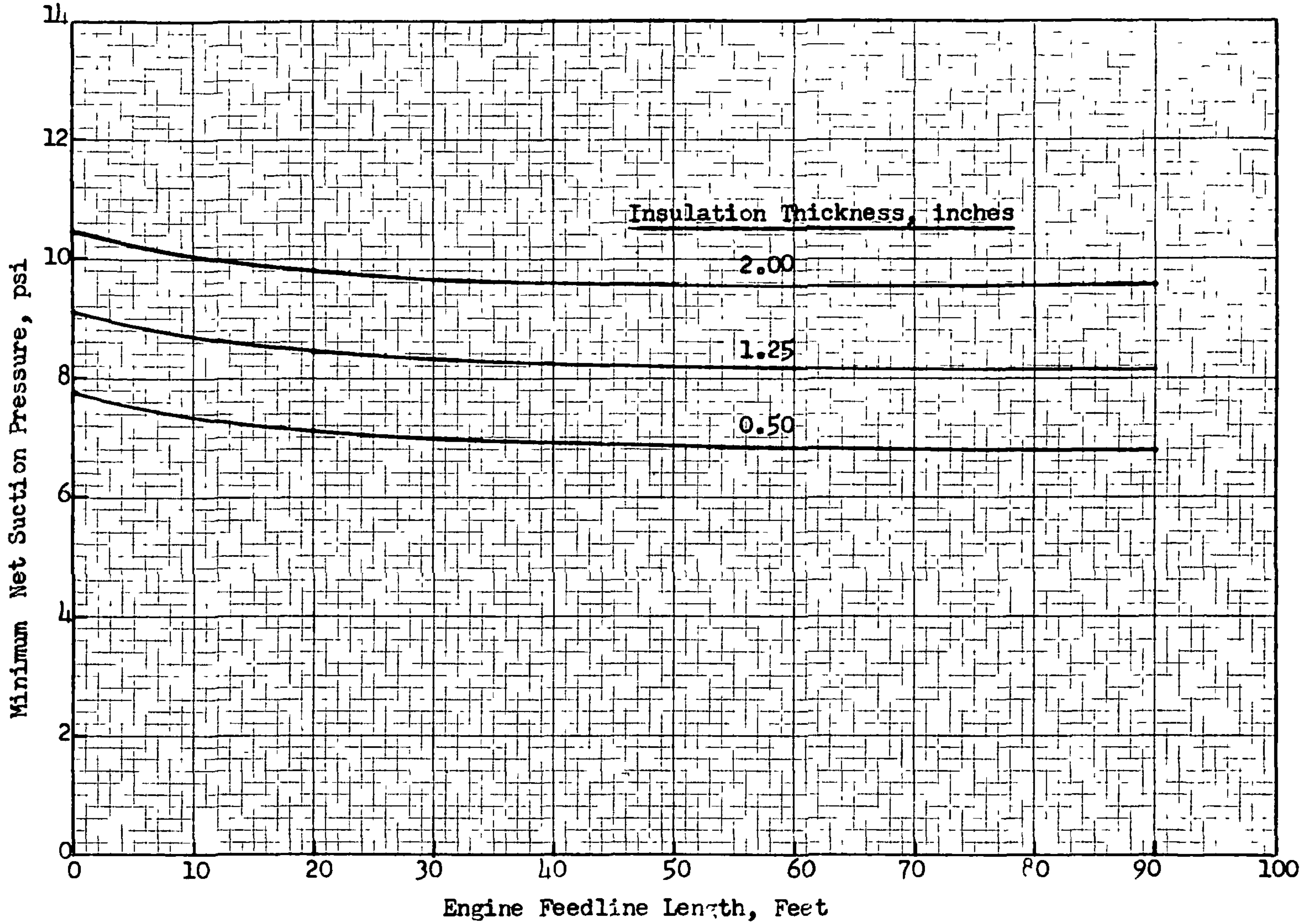


Fig. C-55 Engine Inlet Net Suction Pressure - Hydrogen Ascent Tank

plotted in Figure C-45 for LO_2. It may be seen that, due to the high side-wall heat flux, the ullage wall temperature climbs to within a few degrees of ambient (530°R) within 20 seconds after the start of the ground-hold period.

Similarly, the ullage-vapor temperature rises rapidly until 300 seconds from the start of ground hold. At this time, the ullage pressure has risen to the vent level (25 psia) and the ullage temperature drops as vapor is vented. At 396 seconds, the vent valve is closed and draining initiated. The ullage-vapor temperature then rapidly approaches the pressurant inlet temperature (500°R). Addition of pressurant causes a reduction in the liquid evaporation rate which continues to increase throughout the drain period.

Results of parameter variations for oxygen tank runs are plotted in Figures C-46 through C-49. Residual ullage-vapor mass at the end of the drain period is plotted in Figure C-46 as a function of pressurant inlet temperature. With no insulation, the effects of variations in pressurant temperature are diminished, as is the total residual vapor mass for a 25 psia vent, but much less affected is the vapor mass for a high-vent pressure. The results plotted in Figure C-47 show that the total pressurant mass required followed a similar pattern.

In order to aid in evaluating effects of bleed gas flowrate on engine performance, the values of maximum required pressurant flowrate have been plotted in Figure C-48.

Values of pressure and temperature of the outflow propellant are used in the APHC to compute net suction pressure values. Minimum NPSP values are plotted in Figure C-49 as a function of insulation thickness. The net suction pressure at a given point is defined as the difference between the fluid-saturation pressure corresponding to the local fluid temperature and the static pressure at that point.

In the results presented below, the minimum values of NSP at the tank outlet occur at the end of the drain period where the acceleration (and thus the hydrostatic pressure head) is decreasing and the propellant outflow temperature is the highest. Values are shown for two feedline lengths, 30 and 90 ft, and at the tank outlet (zero feedline length). It may be seen that the fluid conditions at the tank outlet are insufficient to meet the engine NSP requirements. However, the gravity head at the outlet from the engine feedline is more than sufficient to meet the engine requirements. Figure C-50 is a crossplot of these results showing the variation of minimum outflow NPSP as a function of engine feedline length.

Results of parameter variations for hydrogen tank runs are shown in Figures C-51 through C-55. Figures C-51, C-52, and C-53 show the relatively small effect of variations in insulation thickness on residual-vapor mass, total pressurant mass, and maximum pressurant flowrate. Minimum available NPSP values are plotted in Figures C-54 and C-55. These results show that outflow NPSP values are considerably above engine requirements even at the tank outlet. Because of its relatively low density, the increase in NPSP due to increasing gravity head with increasing feedline lengths is overcome by the increasing frictional pressure drop.

The assumption was made that liquid-vapor mixing during the low-g coast prior to engine ignition does not cause ullage-pressure collapse. (The coast period is only 20 seconds in duration.) However, high boundary-layer velocities occur in some cases just prior to booster engine shutdown (e.g., 0.4 fps in the LOX ascent tank with no insulation). These high boundary-layer velocities will result in boundary-layer breakthrough with resultant increased liquid vaporization and some decrease in ullage pressure. The values of pressure rise should, therefore, be regarded as maximum values.

Appendix D

INSTRUMENTATION AND CONTROL

The Instrumentation and Control Analyses were performed to define the methods of controlling the subsystems and to modify the subsystems to provide the most effective concepts for control. A partially Integrated System was selected for examination which consisted of:

(1) Integrated OMPS/ACPS Supply
(2) Subcritical Auxiliary Power Supply
(3) Integrated Fuel Cell/Life Support Supply

The analyses provided the Instrumentation and Control schematics and the associated monitor list. The fail operational/fail safe redundancy requirements were met throughout the examinations.

D.1 INTEGRATED OMPS/ACPS SYSTEMS

The control loops are designed to meet the requirements of the system functional schematic as indicated in Figure D-1. The selected schematic employed the pump-at-the-tank concept. This schematic had been previously revised to provide an effective control approach:

The following results provide the necessary information:

Figure D-1	Functional Schematic, Integrated OMPS/ACPS Pump-at-Tank, Cryogenic Supply System
Figure D-2	Fluid Conditioning Controls
Figure D-3	LH_2 Tank - Helium Pressurization Control
Figure D-4	GH_2 Pressure Controls for Attitude Control Thrusters
Figure D-5	GO_2 Pressure Controls for Attitude Control Thrusters

The typical control loops described herein are ON-OFF and open loop; consisting of a sensor, sensor output electronics, failure detection/isolation circuitry and a fluid control actuator.

All sensors (T10, P9, PS05, etc.) indicated on the control schematics actually consist of four (4) identical sensing elements plus associated failure detection and isolation circuitry - to assure proper sensing information in the event of one (1) or two (2) individual sensor malfunctions.

Figure D-2, Fluid Conditioning Controls, covers the control requirements for the system starting with the gas turbine/pump assemblies and flowing through to either the OM engine(s) inlets or to the gas accumulators. The flow from each pump is valved either to an engine inlet valve or to a heat exchanger where the liquid is converted to a gas and charges an accumulator. Gas from the accumulators is pressure-reduced and fed to the attitude control thrusters or is fed back to the gas generators which provide a heat input to the liquid-to-gas heat exchangers. This is effectively a boot-strap control and requires that the accumulators be pre-charged from ground connections (QD03 and QD04) prior to launch.

The O_2 side has three (3) identical control loops which provide conditioned LO_2 to the engine inlet or conditioned GO_2 to the O_2 accumulator. The H_2 side has three (3) identical control loops which provide conditioned LH_2 to the engine inlet or conditioned GH_2 to the H_2 accumulator - plus an additional dedicated control loop which provides conditioned GH_2 to the H_2 accumulator only.

Each of the three (3) OM engines has a single LO_2 loop and a single LH_2 loop which feeds that engine exclusively. A single failure in either loop will disable both O_2 and H_2 loops and disable the particular engine involved.

Two conditions must be met prior to starting an engine burn: (1) the accumulators must be up to operating pressure (2000 psia) and (2) the pump outlet pressure must be at rated operating pressure (1000 psia). The engine inlet valves are "locked out" until both requirements are met.

A normal OM firing requires two (2) engines. A single failure will still leave double engine burn capability, but a subsequent failure will leave only single-engine burn capability.

Figure D-6, LO_2 and LH_2 Tanks and Pumps Thermal Conditioning Controls, describes the control and sequencing of the GH_2 propellant as it is fed from the LH_2 tank and is supplied to the heat exchanger for H_2 pump inlets, the O_2 pump inlets, or the LO_2 tank. This portion of the overall functional flow schematic (Figure D-11) is shown separately for clarity in Figure D-12. To make this system work requires that at least one H_2 pump inlet heat exchanger valve be always open - SV13-4 valve has been selected for this purpose and will be electrically biased to the open position during operation. A demand for cooling from the T2 transducer only will open the SV15-1 and -2 valves. A cooling demand from either the T1 transducer or T8-T9-T10 will inhibit or disable the SV15 valves and provide cooling for the LO_2 tank and/or the O_2 pump inlet heat exchangers.

All of the control loops consist of three (3) identical loops which are used sequentially, in the event of failures, to meet the fail operational/fail operational requirement. The exception to this is the vent valve control - which can be exempted from the double fail operational requirement due to the burst disc/relief valve backup capability.

The results of these evaluations apply to any orbiter with a cryogenic OMPS and ACPS.

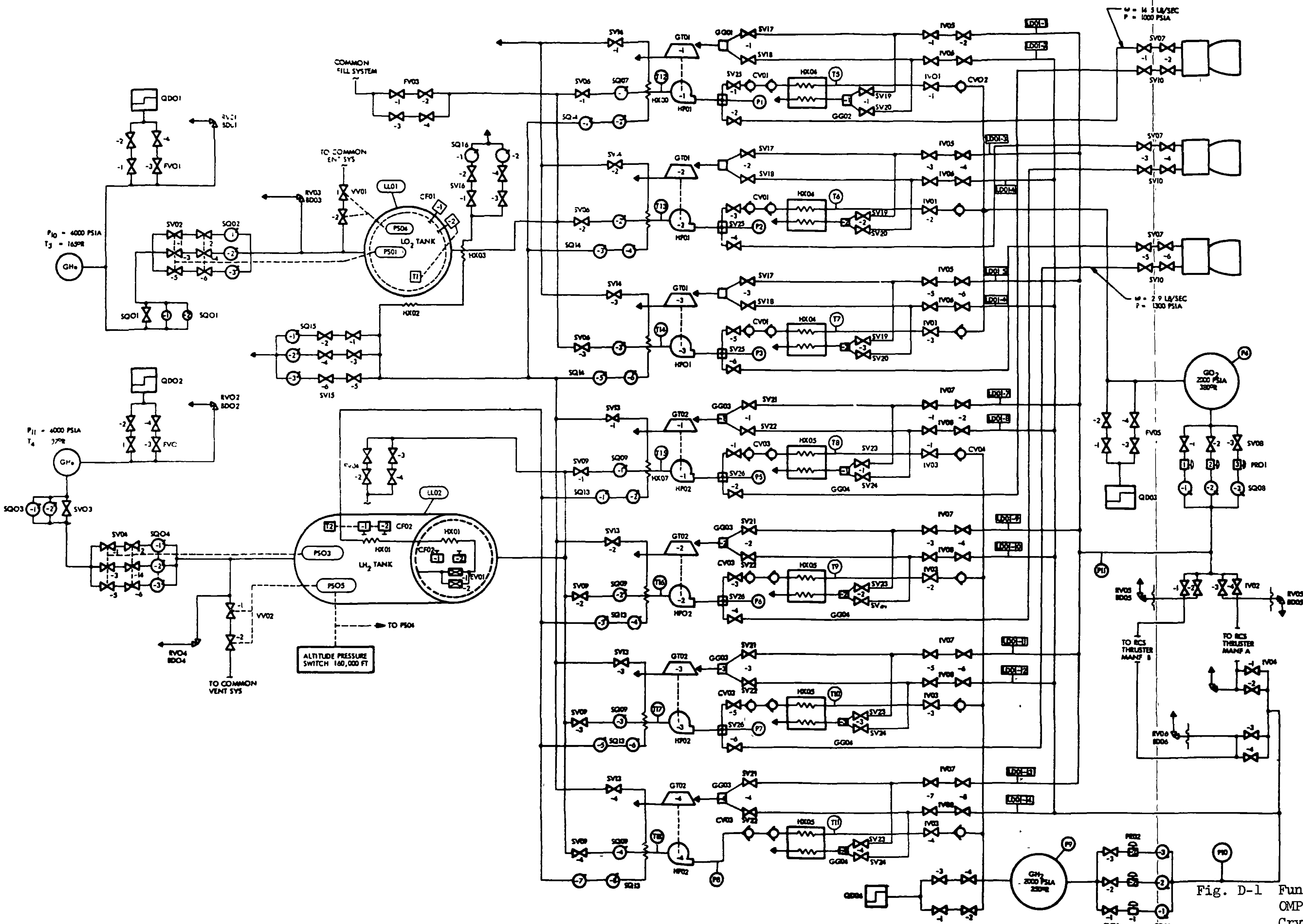


Fig. D-1 Functional Schematic, Integrated OMPS/ACPS Pump at Tank, Cryogenic Supply System

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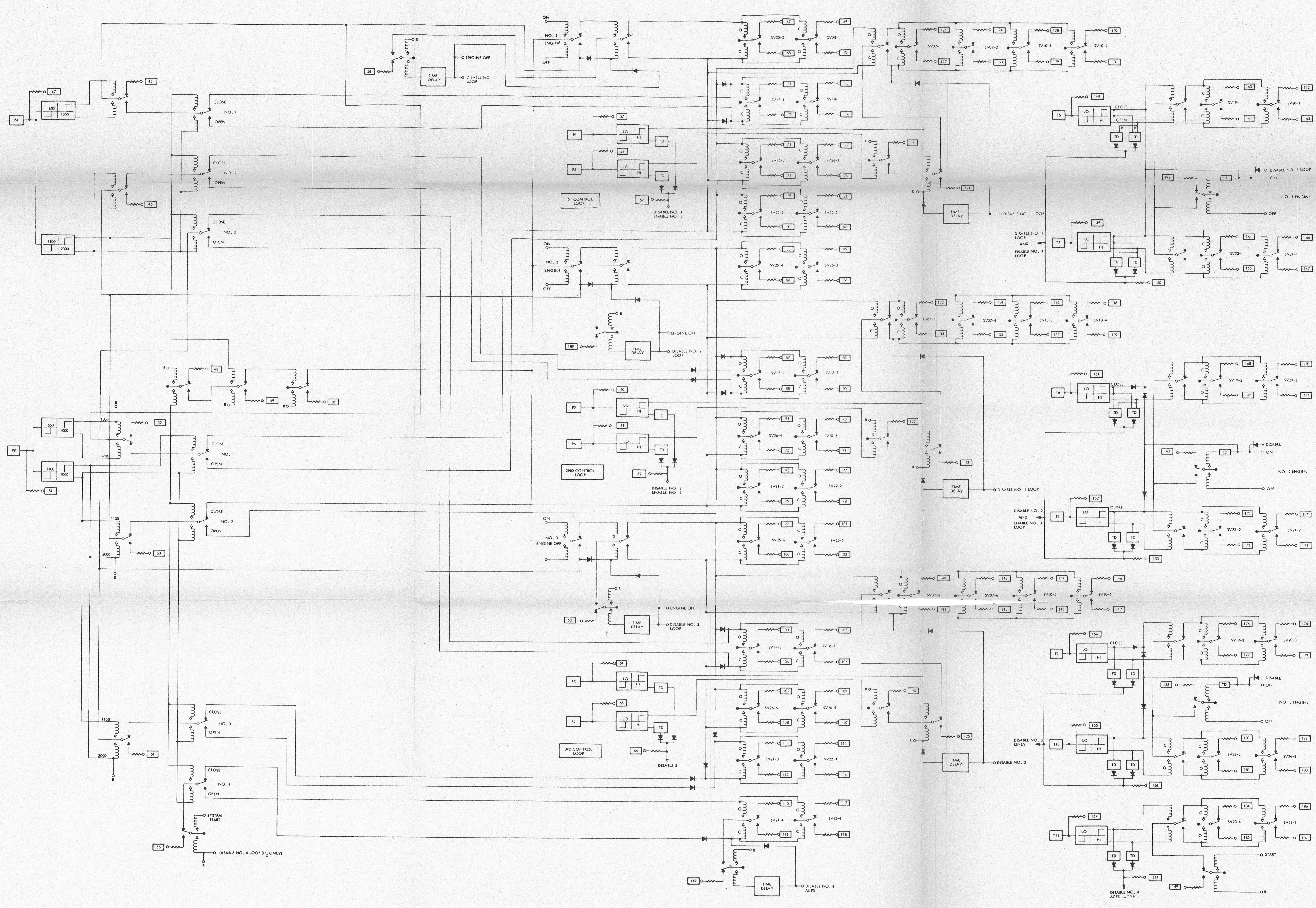

Fig. D-2 Fluid Conditioning Controls

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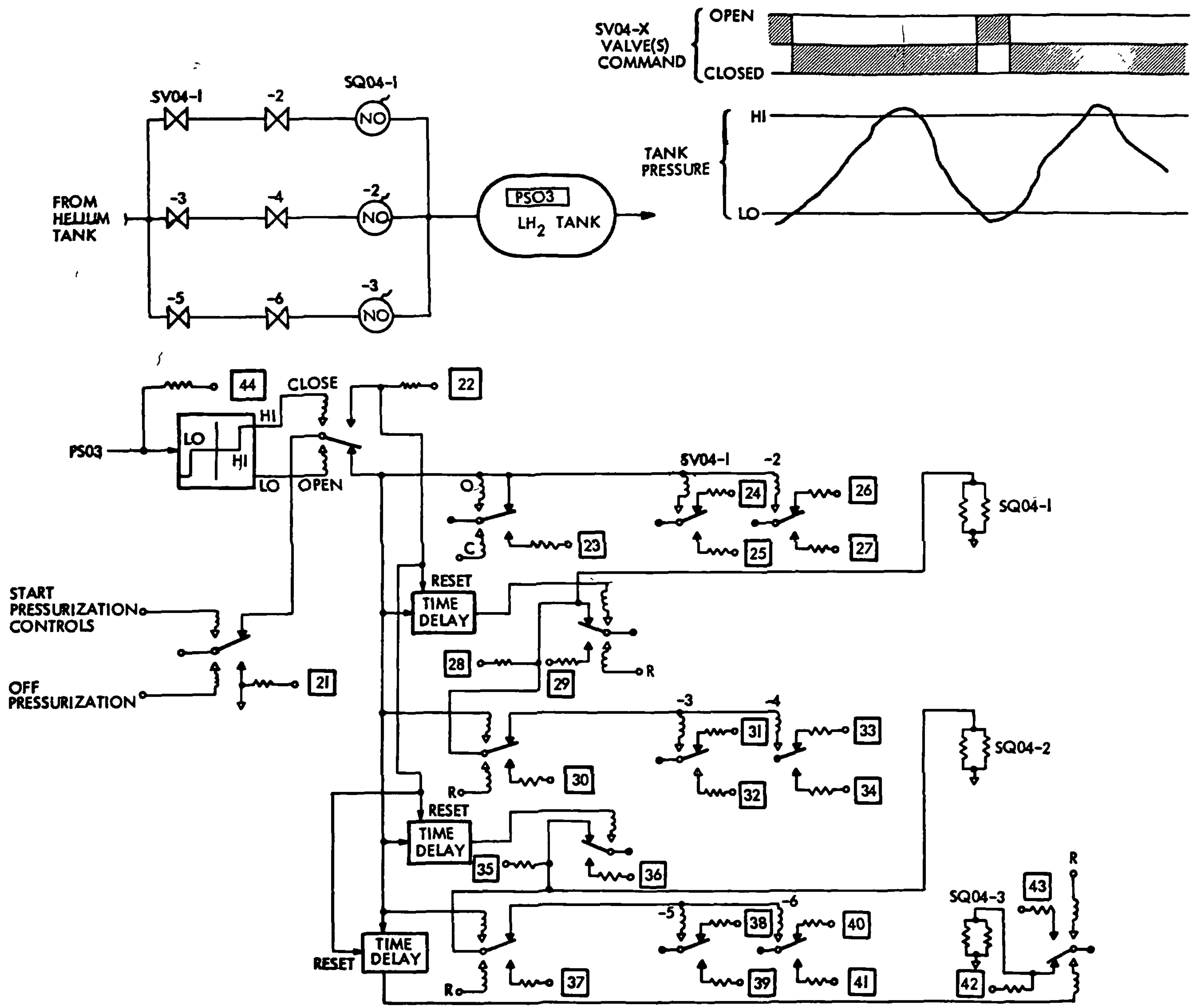

ASSUMPTIONS

1. Acceptance testing completed. All valves operating properly and no leakage in system.

2. SV04 control valves are normally closed solenoid operated valves. These valves open when power is applied and close when power is removed.

3. The SQ04 valves are normally open, squib-actuated valves.

ON-OFF PRESSURIZATION CONTROLS - The control loop consists of a quad-redundant pressure limit switch, (3) sets of ON/OFF valving, and associated logic and control electronics.

The output of the pressure switch energizes a normally open relay which closes and sends and "open" signal to the first set of control valves (SV04-1 and -2). This command is also sent to the driving relay for SV04-3 and -4, and SV04-5 and -6, but power to these relays is locked out until a failure occurs in the previous set of control valves.

A signal is also sent to a time delay circuit simultaneous with the SV03 "open" signal. If the pressure does not increase above the pressure setting of the limit switch in a certain period of time (based on nominal response time of system) indicating valve(s) malfunction, the time delay circuit will deactivate the first set of control valves by actuating SQ04-11 closed and activating the second set of control valves (SV04-3 and -4).

This process is repeated for a malfunction of SV04-3 and -4, in which case SQ04-2 is closed and SV04-5 and -6 are activated.

This is basically a minimum pressure control loop - that is, the controls maintain the tank pressure at or above a set low limit. The upper limit of the tank pressure is controlled by the vent valve and PS05 (pressure switch) controls.

Fig. D-3 LH_2 Tank - Helium Pressurization Control

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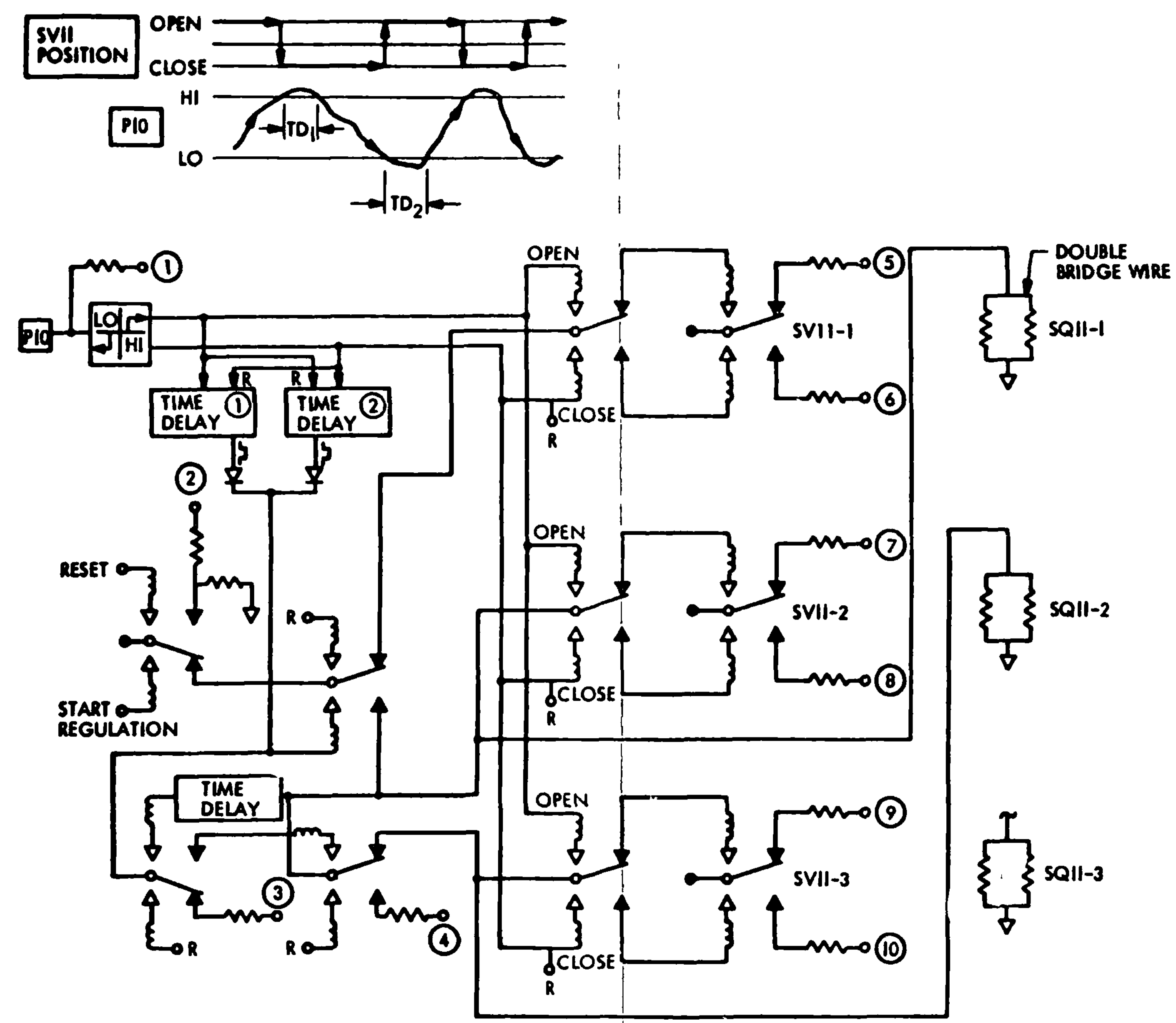

Fig. D-4 GH_2 Pressure Controls for Attitude Control Thrusters

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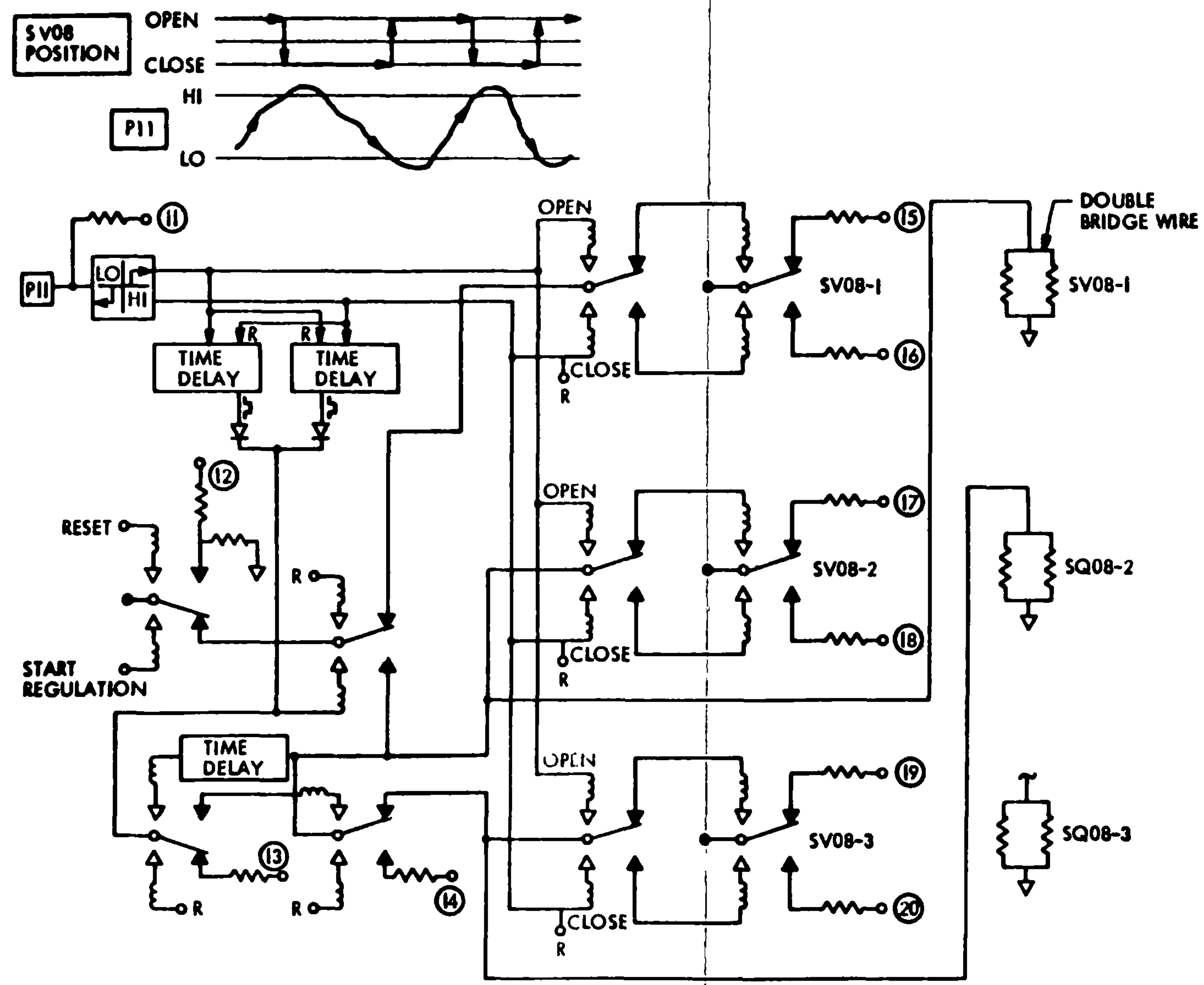

Fig. D-5 GO_2 Pressure controls for Attitude Control Thrusters

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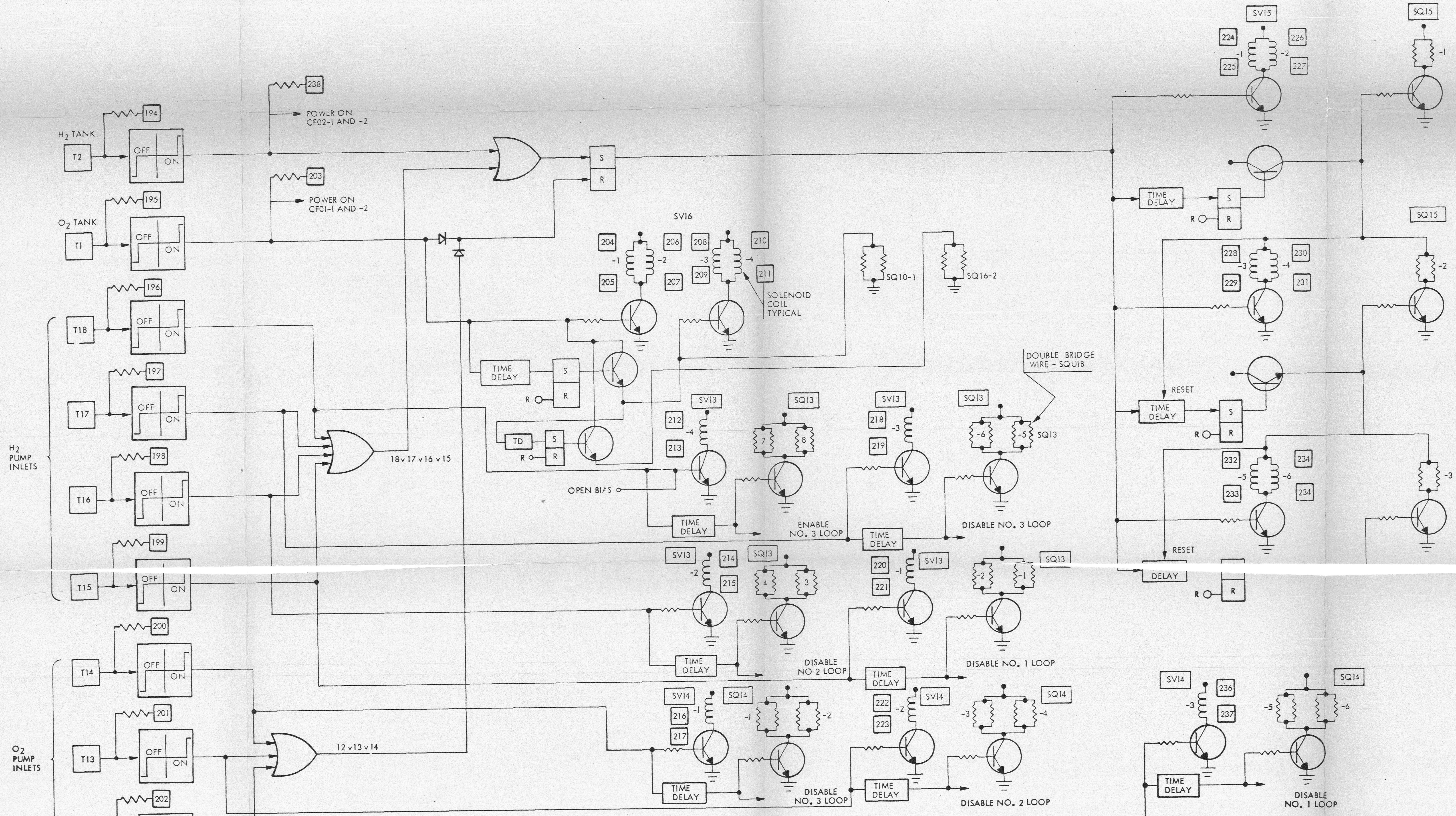

TEMPERATURE XDUCERS				CONTROL VALVE(S) POSITION			
T2	T1	T3 v T4 v T5 v T6 T15 v T16 v T17 v T18	T12 v T13 v T14	SV15 SQ15	SV16	* SV13 & SQ13	SV14 & SQ14
HIGH	HIGH	HIGH	HIGH	CLOSED	OPEN	OPEN	OPEN
HIGH	LOW	LOW	LOW	OPEN	CLOSED	CLOSED	CLOSED
LOW	LOW	HIGH	LOW	CLOSED	CLOSED	OPEN	CLOSED

*SV13-4 BIASED OPEN DURING ALL OPERATING TIMES

Fig. D-6 LO_2 and LH_2 Tanks and Pumps Thermal Conditioning Controls and Failure Detection Isolation

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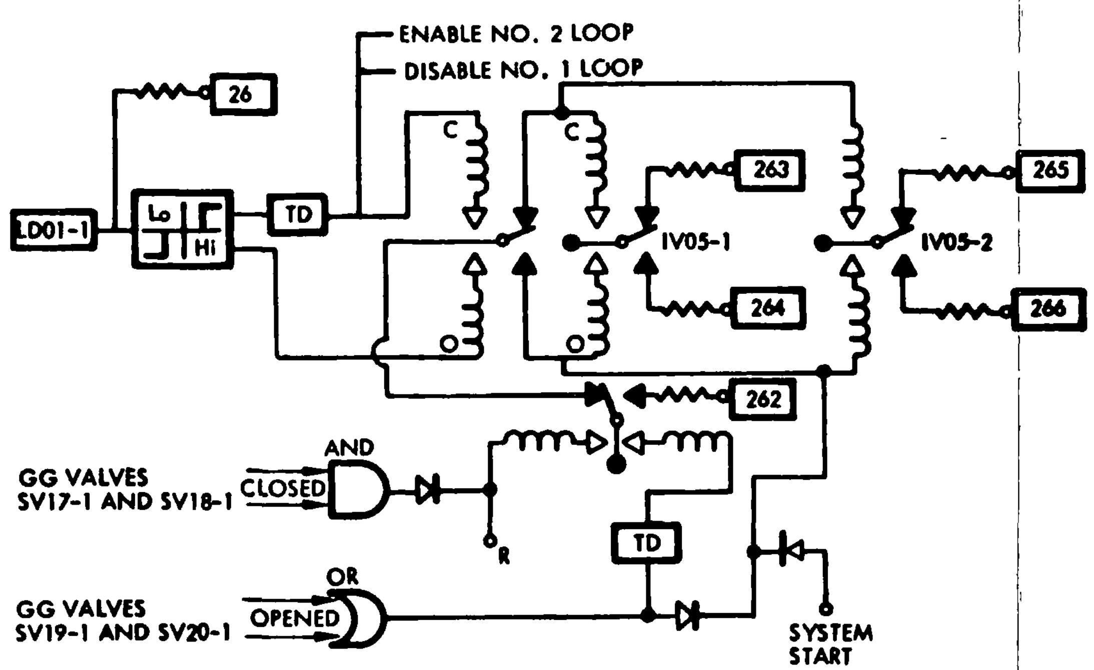

LEAK DETECTOR NO.	GG VALVES NO.	ISOLATION VALVES NO.	LOOP DISABLE
LD01-1	SV17-1, SV19-1	IV05-1, IV05-2	NO. 1
-2	SV18-1, SV20-1	IV06-1, IV06-2	NO. 1
-3	SV17-2, SV19-2	IV05-3, IV05-4	NO. 1
-4	SV18-2, SV20-2	IV06-3, IV06-4	NO. 1
-5	SV17-3, SV19-3	IV05-5, IV05-6	NO. 2
-6	SV18-3, SV20-3	IV06-5, IV06-6	NO. 2
-7	SV21-1, SV23-1	IV07-1, IV07-2	NO. 2
-8	SV22-1, SV24-1	IV08-1, IV08-2	NO. 2
-9	SV21-2, SV23-2	IV07-3, IV07-4	NO. 3
-10	SV22-2, SV24-2	IV08-3, IV08-4	NO. 3
-11	SV21-3, SV23-3	IV07-5, IV07-6	NO. 3
-12	SV22-3, SV24-3	IV08-5, IV08-6	NO. 3
-13	SV21-4, SV23-4	IV07-7, IV07-8	NO. 4
-14	SV22-4, SV24-4	IV08-7, IV08-8	NO. 4

Fig. D-7 Typical Gas Generator Valve(s) Leakage Failure Detection Logic

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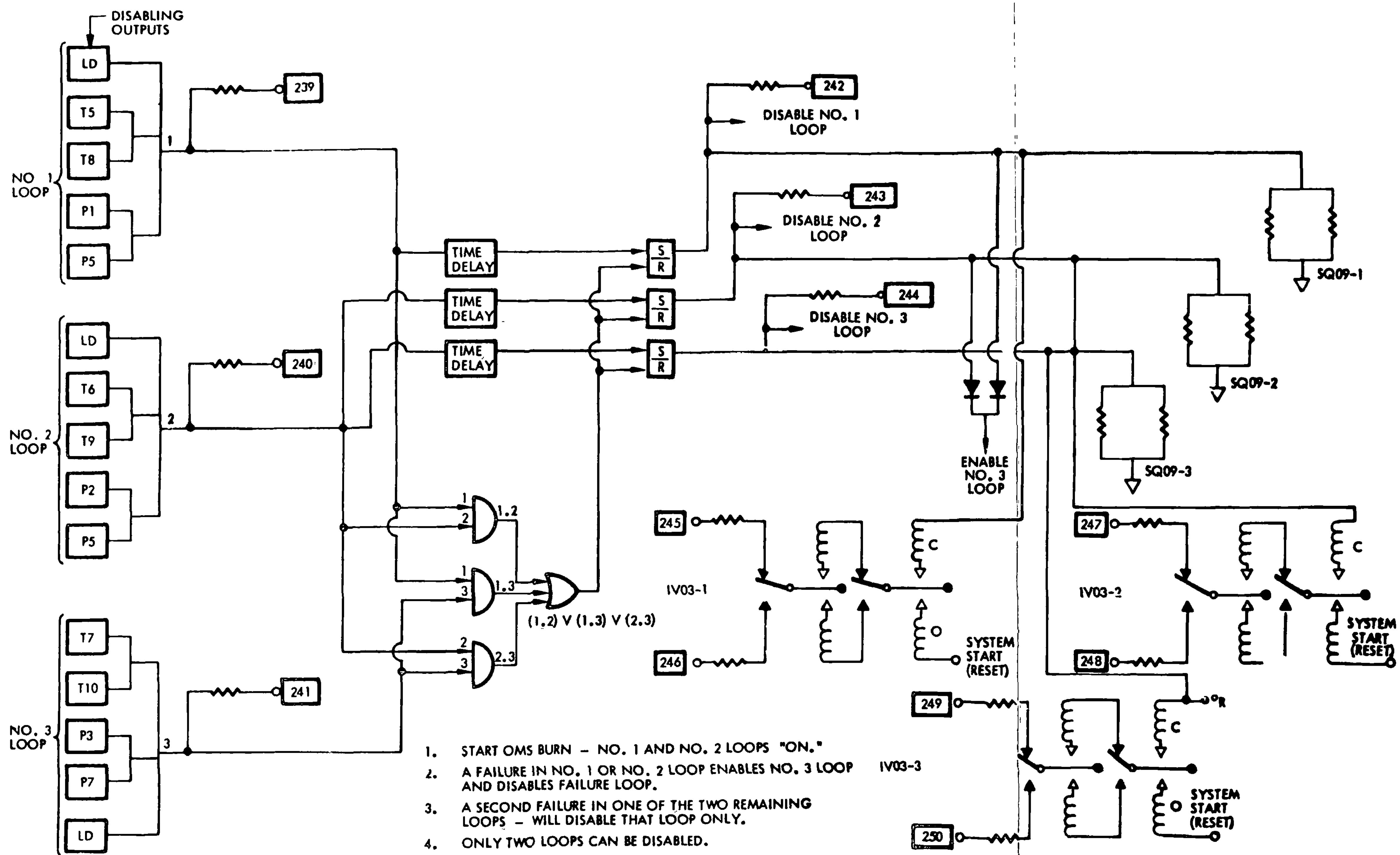

1. START OMS BURN – NO. 1 AND NO. 2 LOOPS "ON."
2. A FAILURE IN NO. 1 OR NO. 2 LOOP ENABLES NO. 3 LOOP AND DISABLES FAILURE LOOP.
3. A SECOND FAILURE IN ONE OF THE TWO REMAINING LOOPS – WILL DISABLE THAT LOOP ONLY.
4. ONLY TWO LOOPS CAN BE DISABLED.

Fig. D-8 Failure Isolation and Control Loop Switching

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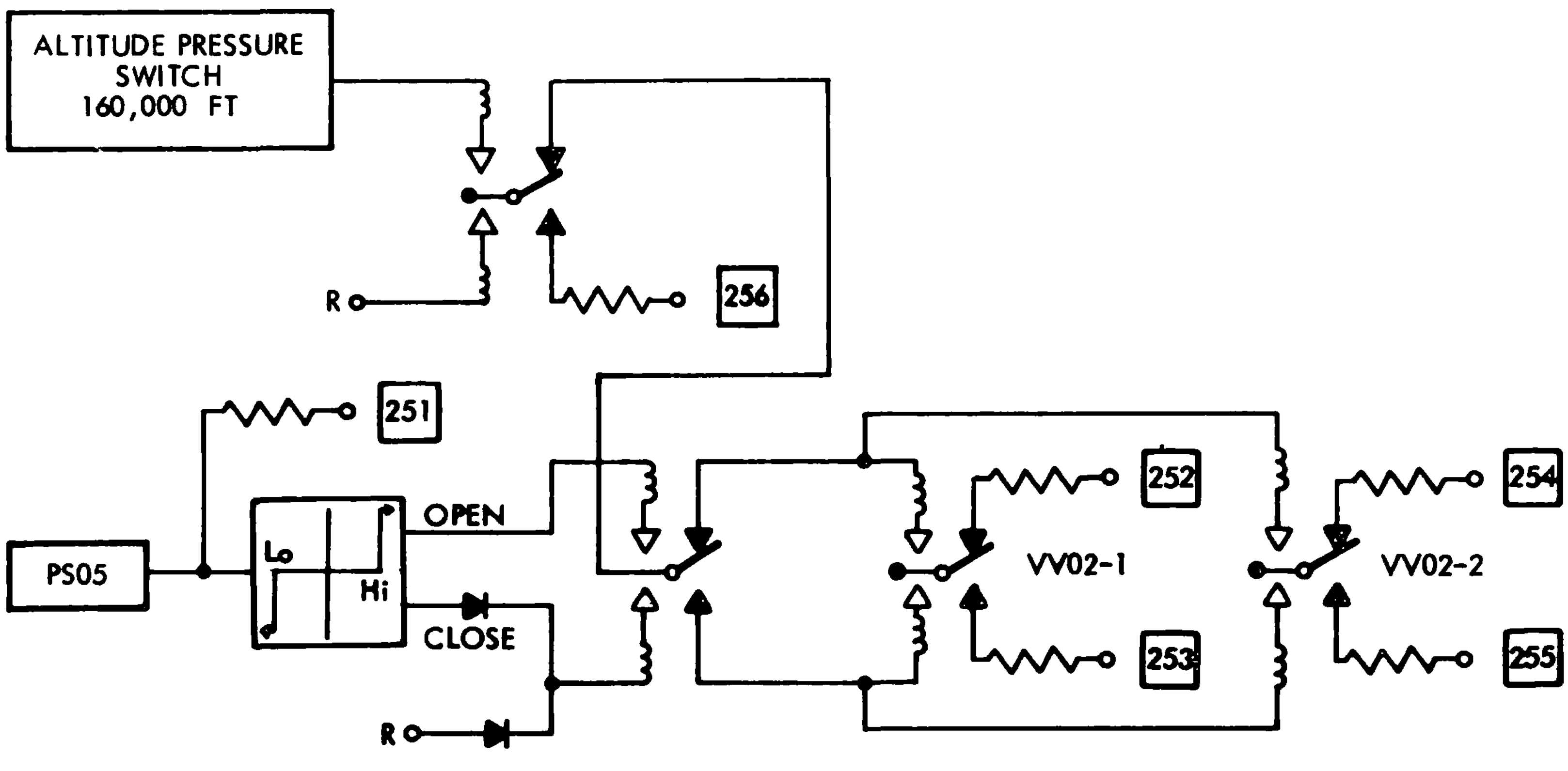

IDENTICAL FOR PS04 AND VV01-1 AND -2 EXCEPT FOR ALTITUDE PRESSURE SWITCH

Fig. D-9 Vent Valve Control and Monitoring Points - LH_2 Tank

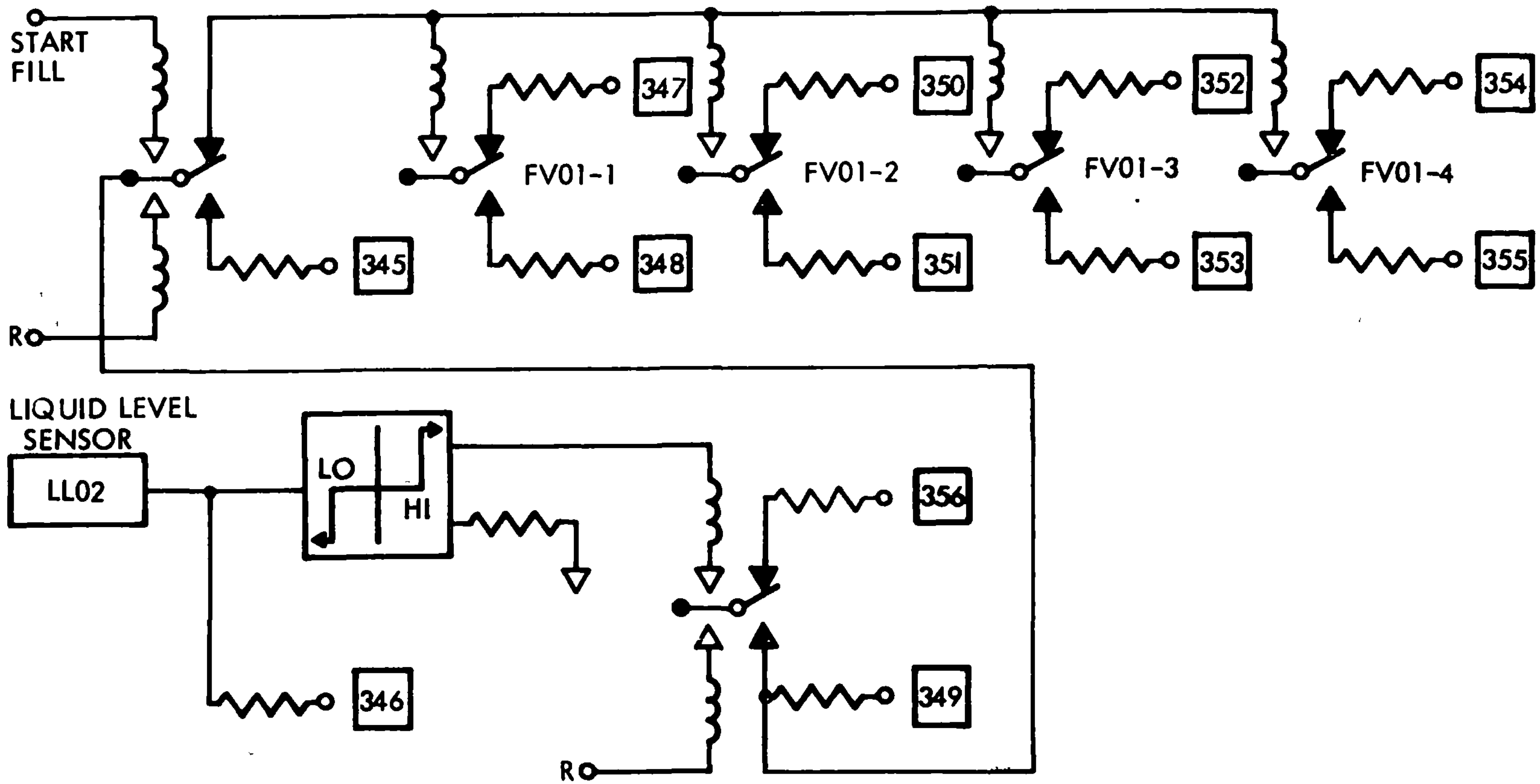

Fig. D-10 Fill Valve Controls

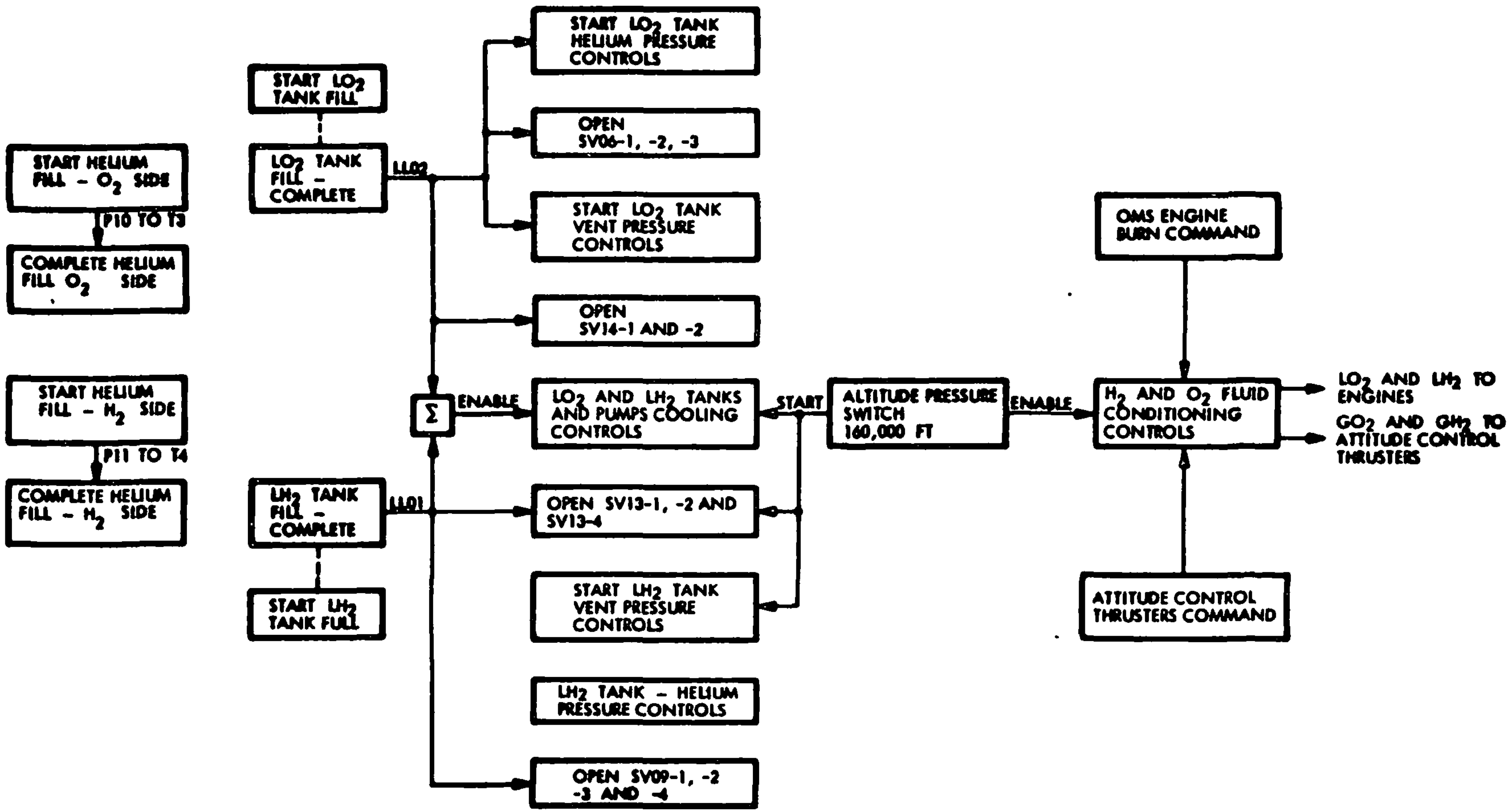

Fig. D-11 Event Flow Chart

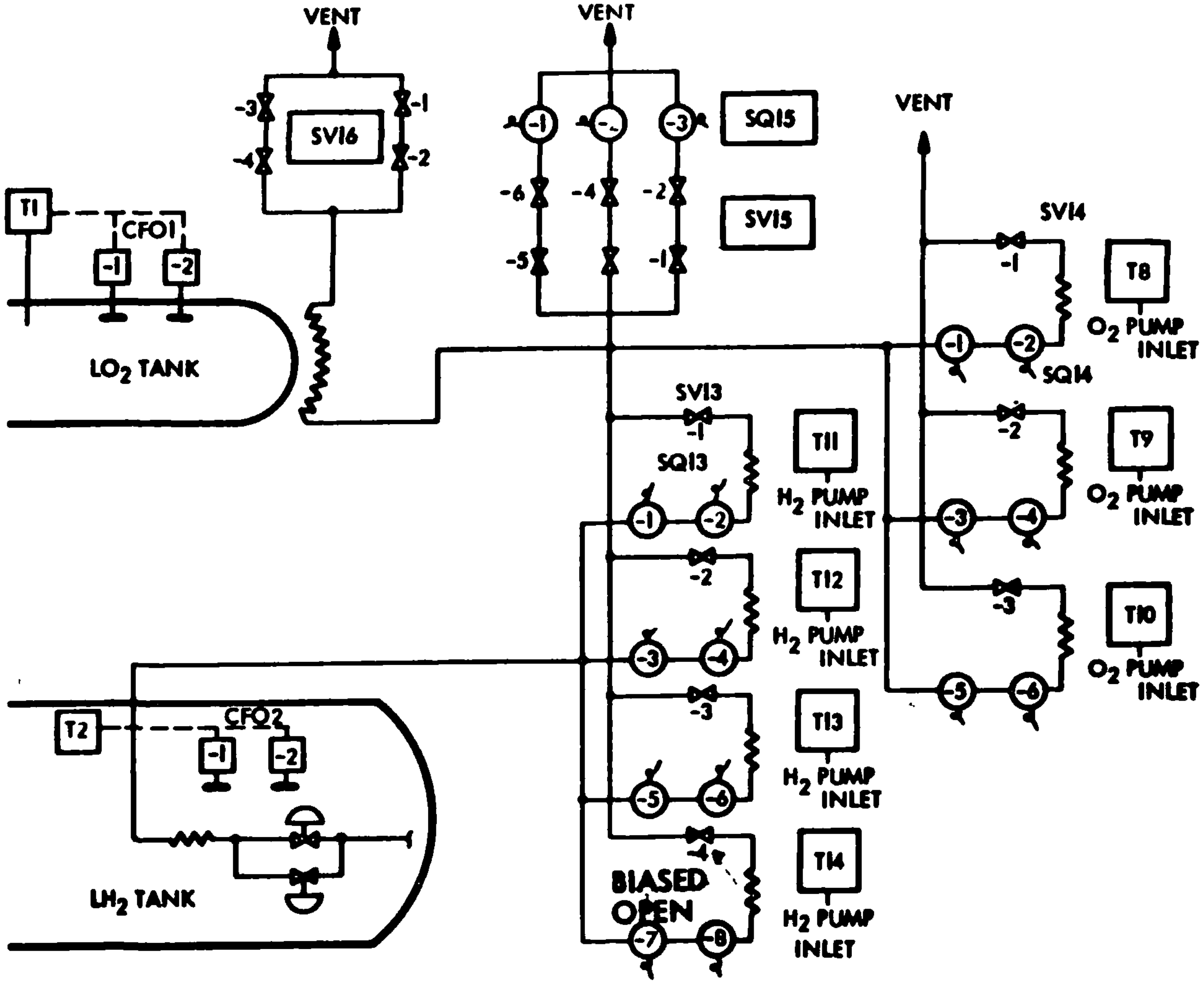

Fig. D-12 LO_2 and LH_2 Tanks and Pumps Thermal Conditioning Controls

LMSC-A991396

Table D-1

INSTRUMENTATION AND CONTROLS MONITOR LIST

INTEGRATED OMPS/ACPS - SINGLE TANK, PUMP-AT-TANK SYSTEM

GH_2 PRESSURIZATION CONTROLS (FIG. D-4)

Monitor Point	Events and Monitor Readout
1	0 to 5 Vdc (P10 Pressure Transducer Analog Output)
2	0 Vdc - START 5 Vdc - RESET (Start Switch)
3	0 Vdc - Indicates (2) failures and 5 with last control valve 5 Vdc - Indicates one or none failures (Power Relay)
4	0 Vdc - Indicates switch to last control valve 5 Vdc - Indicates Reset Condition
5	0 Vdc - SV11-1 CLOSE 5 Vdc - SV11-1 OPEN (SV11-1 Position Indicator Switch)
6	0 Vdc - SV11-1 OPEN 5 Vdc - SV11-1 CLOSE (SV11-1 Position Indicator Switch)
7	0 Vdc - SV11-2 CLOSE 5 Vdc - SV11-2 OPEN (SV11-2 Position Indicator Switch)
8	0 Vdc - SV11-2 OPEN 5 Vdc - SV11-2 CLOSE (SV11-2 Position Indicator Switch)
9	0 Vdc - SV11-3 OPEN 5 Vdc - SV11-3 CLOSE (SV11-3 Position Indicator Switch)
10	0 Vdc - SV11-3 OPEN 5 Vdc - SV11-3 CLOSE (SV11-3 Position Indicator Switch)

GO_2 PRESSURIZATION CONTROLS (FIG. D-5)

Monitor Point	Events and Monitor Readout
11–20	Same as 1 through 10 Except P10 is P11 and SV11 is SV08

LH_2 TANK - HELIUM PRESSURIZATION CONTROLS (FIG. D-3)

Monitor Point	Events and Monitor Readout
21	0 Vdc - Start Pressure Controls Command 5 Vdc - OFF Pressurization
22	0 Vdc - Tank Pressure Above Low Limit 5 Vdc - Low Pressure, PS03 Output Signals Valves to OPEN
23	0 Vdc - Valves SV04-1 and -2 Command OPEN 5 Vdc - Deenergize SV04-1 and -2
24	0 Vdc - SV04-1 CLOSE 5 Vdc - SV04-1 OPEN
25	0 Vdc - SV04-1 OPEN 5 Vdc - SV04-1 CLOSE
26	0 Vdc - SV04-2 CLOSE 5 Vdc - SV04-2 OPEN
27	0 Vdc - SV04-2 OPEN 5 Vdc - SV04-2 CLOSE
28	0 Vdc - Deactivate SV04-3 and SV04-4 Control Valves 5 Vdc - Activate SV04-3 and -4 Control Valves. SQ04-1 CLOSE
29	0 Vdc - Activate SV04-1 and -4 Control Valves 5 Vdc - Activate 1st Set of Valves (RESET or START Condition)
30	0 Vdc - Power ON SV04-3 and -4 5 Vdc - Power OFF SV03-3 and -4
31	0 Vdc - SV04-3 CLOSE 5 Vdc - SV04-3 OPEN
32	0 Vdc - SV04-3 OPEN 5 Vdc - SV04-3 CLOSE
33	0 Vdc - SV04-4 CLOSE 5 Vdc - SV04-4 OPEN
34	0 Vdc - SV04-4 OPEN 5 Vdc - SV04-4 CLOSE
35	0 Vdc - Deactivate 3rd Set of Valves 5 Vdc - Activate 3rd Set of Control Valves

LH_2 TANK - HELIUM PRESSURIZATION CONTROLS - contd

Monitor Point	Events and Monitor Readout
36	0 Vdc - Activate 3rd Set of Control Valves 5 Vdc - Deactivate 2nd Set of Valves
37	0 Vdc - Power ON SV04-5 and -6 OPEN 5 Vdc - Power OFF SV04-5 and -6 CLOSE
38	0 Vdc - SV04-5 CLOSE 5 Vdc - SV04-5 OPEN
39	0 Vdc - SV04-5 OPEN 5 Vdc - SV04-5 CLOSE
40	0 Vdc - SV04-6 CLOSE 5 Vdc - SV04-6 OPEN
41	0 Vdc - SV04-6 OPEN 5 Vdc - SV04-6 CLOSE
42	0 Vdc - SQ04-3 OPEN 5 Vdc - SQ04-3 CLOSE
43	0 Vdc - SQ04-3 CLOSE 5 Vdc - SQ04-3 OPEN
44	0 Vdc - High-Pressure Position 5 Vdc - Low-Pressure Position (PS03 Pressure Switch Assembly Output)

FLUID CONDITIONING CONTROLS (FIG. D-2)

Monitor Point	Events and Monitor Readout
45	0 Vdc - ENABLE 5 Vdc - DISABLE (Enable/Disable Relay Monitor for No. 1 Output of P4)
46	0 Vdc - ENABLE 5 Vdc - DISABLE (Same as 45 Except No. 2 Output)
47	0 to 5 Vdc (P4 Pressure Transducer Analog Output)
48	0 Vdc - P9 Output < 1980 psi 5 Vdc - P9 Output > 2020 psi { Enable/Disable P9 Output - Engine Burn Relay Monitor
49	0 Vdc - P4 Output > 2020 psi 5 Vdc - P4 Output < 1980 psi and P9 Output > 2020 psi { Enable/Disable P4 Output - Engine Burn Relay Monitor
50	0 Vdc - P4 and Pr Outputs > 2020 psi (No. 1, 2 and 3 Engine ON/OFF Relays ENABLED) 5 Vdc - P4 and/or P9 Outputs < 1980 psi { Enable/Disable P4 and P9 Output Engine Burn Relay Monitor
51	0 to 5 Vdc (P9 Pressure Transducer Analog Output)
52	0 Vdc - ENABLE 5 Vdc - DISABLE (Enable/Disable Relay Monitor for No. 1 Output of P9)
53	Same as 52 Except for No. 2 Output
54	Same as 52 Except for No. 3 Output
55	Same as 52 Except for No. 5 Output
56	0 Vdc - ENABLE 5 Vdc - DISABLE (No. 1 Engine Loop Relay Monitor)
57	0 to 5 Vdc (P1 Pressure Transducer Analog Output)
58	0 to 5 Vdc (P5 Pressure Transducer Analog Output)
59	0 Vdc - No Failure 5 Vdc - Failure (P1 and/or P5 Failure Indication Output)
60	0 to 5 Vdc (P2 Pressure Transducer Analog Output)
61	0 to 5 Vdc (P6 Pressure Transducer Analog Output)

FLUID CONDITIONING CONTROLS - contd

Monitor Point	Events and Monitor Readout	
62	0 Vdc - No Failure 5 Vdc - Failure	(P2 and/or P6 Failure Indication Output)
63	0 Vdc - ENABLE 5 Vdc - DISABLE	(No. 3 Engine Loop Relay Monitor)
64	0 to 5 Vdc (P3 Pressure Transducer Analog Output)	
65	0 to 5 Vdc (P7 Pressure Transducer Analog Output)	
66	0 Vdc - No Failure 5 Vdc - Failure	(P3 and/or P7 Failure Indication Monitor)
67	0 Vdc - SV25-2 CLOSE 5 Vdc - SV25-2 OPEN	Valve Position Switch Monitor (VPSM)
68	0 Vdc - SV25-2 OPEN 5 Vdc - SV25-2 CLOSE	Valve Position Switch Monitor (VPSM)
69	0 Vdc - SV25-1 OPEN 5 Vdc - SV25-1 CLOSE	Valve Position Switch Monitor (VPSM)
70	0 Vdc - SV25-1 CLOSE 5 Vdc - SV25-1 OPEN	Valve Position Switch Monitor (VPSM)
71	0 Vdc - SV17-1 CLOSE 5 Vdc - SV17-1 OPEN	Valve Position Switch Monitor (VPSM)
72	0 Vdc - SV17-1 OPEN 5 Vdc - SV17-1 CLOSE	Valve Position Switch Monitor (VPSM)
73	0 Vdc - SV18-1 CLOSE 5 Vdc - SV18-1 OPEN	Valve Position Switch Monitor (VPSM)
74	0 Vdc - SV18-1 OPEN 5 Vdc - SV18-1 CLOSE	Valve Position Switch Monitor (VPSM)
75	0 Vdc - SV26-2 CLOSE 5 Vdc - SV26-2 OPEN	Valve Position Switch Monitor (VPSM)
76	0 Vdc - SV26-2 OPEN 5 Vdc - SV26-2 CLOSE	Valve Position Switch Monitor (VPSM)

FLUID CONDITIONING CONTROLS - contd

Monitor Point		Events and Monitor Readout
77	0 Vdc - SV26-1 CLOSE 5 Vdc - SV26-1 OPEN	Valve Position Switch Monitor (VPSM)
78	0 Vdc - SV26-1 OPEN 5 Vdc - SV26-1 CLOSE	
79	0 Vdc - SV21-1 CLOSE 5 Vdc - SV21-1 OPEN	
80	0 Vdc - SV21-1 OPEN 5 Vdc - SV21-1 CLOSE	
81	0 Vdc - SV22-1 CLOSE 5 Vdc - SV22-1 OPEN	
82	0 Vdc - SV22-1 OPEN 5 Vdc - SV22-1 CLOSE	
83	0 Vdc - SV25-4 CLOSE 5 Vdc - SV25-4 OPEN	
84	0 Vdc - SV25-4 OPEN 5 Vdc - SV25-4 CLOSE	
85	0 Vdc - SV25-3 OPEN 5 Vdc - SV25-3 CLOSE	
86	0 Vdc - SV25-3 CLOSE 5 Vdc - SV25-3 OPEN	
87	0 Vdc - SV17-2 CLOSE 5 Vdc - SV17-2 OPEN	
88	0 Vdc - SV17-2 OPEN 5 Vdc - SV17-2 CLOSE	
89	0 Vdc - SV18-2 CLOSE 5 Vdc - SV18-2 OPEN	
90	0 Vdc - SV18-2 CLOSE 5 Vdc - SV18-2 OPEN	
91	0 Vdc - SV26-4 CLOSE 5 Vdc - SV26-4 OPEN	
92	0 Vdc - SV26-4 OPEN 5 Vdc - SV26-4 CLOSE	

FLUID CONDITIONING CONTROLS - contd

Monitor Point		Events and Monitor Readout
93	0 Vdc - SV26-3 CLOSE 5 Vdc - SV26-3 OPEN	Valve Position Switch Monitor (VPSM)
94	0 Vdc - SV26-3 OPEN 5 Vdc - SV26-3 CLOSE	
95	0 Vdc - SV21-2 CLOSE 5 Vdc - SV21-2 OPEN	
96	0 Vdc - SV21-2 OPEN 5 Vdc - SV21-2 CLOSE	
97	0 VDC - SV22-2 CLOSE 5 Vdc - SV22-2 OPEN	
98	0 Vdc - SV22-2 OPEN 5 Vdc - SV22-2 CLOSE	
99	0 Vdc - SV25-6 CLOSE 5 Vdc - SV25-6 OPEN	
100	0 Vdc - SV25-6 OPEN 5 Vdc - SV25-6 CLOSE	
101	0 Vdc - SV25-5 OPEN 5 Vdc - SV25-5 CLOSE	
102	0 Vdc - SV25-5 CLOSE 5 Vdc - SV25-5 OPEN	
103	0 Vdc - SV17-3 CLOSE 5 Vdc - SV17-3 OPEN	
104	0 Vdc - SV17-3 OPEN 5 Vdc - SV17-3 CLOSE	
105	0 Vdc - SV18-3 CLOSE 5 Vdc - SV18-3 OPEN	
106	0 Vdc - SV18-3 OPEN 5 Vdc - SV18-3 CLOSE	
107	0 Vdc - SV26-6 CLOSE 5 Vdc - SV26-6 OPEN	
108	0 Vdc - SV26-6 OPEN 5 Vdc - SV26-6 CLOSE	

FLUID CONDITIONING CONTROLS - contd

Monitor Point	Events and Monitor Readout	
109	0 Vdc - SV26-5 CLOSE 5 Vdc - SV26-5 OPEN	Valve Position Switch Monitor (VPSM)
110	0 Vdc - SV26-5 OPEN 5 Vdc - SV26-5 CLOSE	
111	0 Vdc - SV21-3 CLOSE 5 Vdc - SV21-3 OPEN	
112	0 Vdc - SV21-3 OPEN 5 Vdc - SV21-3 CLOSE	
113	0 Vdc - SV22-3 CLOSE 5 Vdc - SV22-3 OPEN	
114	0 Vdc - SV22-3 OPEN 5 Vdc - SV22-3 CLOSE	
115	0 Vdc - SV21-4 CLOSE 5 Vdc - SV21-4 OPEN	
116	0 Vdc - SV21-4 OPEN 5 Vdc - SV21-4 CLOSE	
117	0 Vdc - SV22-4 CLOSE 5 Vdc - SV22-4 OPEN	
118	0 Vdc - SV22-4 OPEN 5 Vdc - SV22-4 CLOSE	
119	0 Vdc - Power ON 5 Vdc - Power OFF	(Power Relay Monitor for SV21-4 and SV22-4)
120	0 Vdc - ENABLE (P5 ≥ Rated Operating Pressure) 5 Vdc - DISABLE (P5 < Rated Operating Pressure)	Enable/Disable Relay Monitor for No. 1 Loop Engine Valves
121	Same as 120 above Except for P1.	
122	0 Vdc - ENABLE (P6 ≥ Rated Operating Pressure) 5 Vdc - DISABLE (P6 < Rated Operating Pressure)	Enable/Disable Relay Monitor for No. 2 Loop Engine Valves
123	Same as 122 above Except for P2.	
124	0 Vdc - ENABLE (P7 ≥ Rated Operating Pressure) 5 Vdc - DISABLE (P7 < Rated Operating Pressure)	Enable/Disable Relay Monitor for No. 3 Loop Engine Valves
125	Same as 124 above Except for P3.	

FLUID CONDITIONING CONTROLS - contd

Monitor Point		Events and Monitor Readout
126	0 Vdc - SV07-1 CLOSE 5 Vdc - SV07-1 OPEN	Valve Position Switch Monitor (VPSM)
127	0 Vdc - SV07-1 OPEN 5 Vdc - SV07-1 CLOSE	
128	0 Vdc - SV10-1 CLOSE 5 Vdc - SV10-1 OPEN	
129	0 Vdc - SV10-1 OPEN 5 Vdc - SV10-1 CLOSE	
130	0 Vdc - SV10-2 CLOSE 5 Vdc - SV10-2 OPEN	
131	0 Vdc - SV10-2 OPEN 5 Vdc - SV10-2 CLOSE	
132	0 Vdc - SV07-3 CLOSE 5 Vdc - SV07-3 OPEN	
133	0 Vdc - SV07-3 OPEN 5 Vdc - SV07-3 CLOSE	
134	0 Vdc - SV07-4 CLOSE 5 Vdc - SV07-4 OPEN	
135	0 Vdc - SV07-4 OPEN 5 Vdc - SV07-4 CLOSE	
136	0 Vdc - SV10-3 CLOSE 5 Vdc - SV10-3 OPEN	
137	0 Vdc - SV10-3 OPEN 5 Vdc - SV10-3 CLOSE	
138	0 Vdc - SV10-4 CLOSE 5 Vdc - SV10-4 OPEN	
139	0 Vdc - SV10-4 OPEN 5 Vdc - SV10-4 CLOSE	
140	0 Vdc - SV07-5 CLOSE 5 Vdc - SV07-5 OPEN	
141	0 Vdc - SV07-5 OPEN 5 Vdc - SV07-5 CLOSE	

FLUID CONDITIONING CONTROLS - contd

Monitor Point	Events and Monitor Readout	
142	0 Vdc - SV07-6 CLOSE 5 Vdc - SV07-6 OPEN	Valve Position Switch Monitor (VPSM)
143	0 Vdc - SV07-6 OPEN 5 Vdc - SV07-6 CLOSE	
144	0 Vdc - SV10-5 CLOSE 5 Vdc - SV10-5 OPEN	
145	0 Vdc - SV10-5 OPEN 5 Vdc - SV10-5 CLOSE	
146	0 Vdc - SV10-6 CLOSE 5 Vdc - SV10-6 OPEN	
147	0 Vdc - SV10-6 OPEN 5 Vdc - SV10-6 CLOSE	
148	0 to 5 Vdc (T5 Temperature Sensor Analog Output)	
149	0 to 5 Vdc (T8 Temperature Sensor Analog Output)	
150	0 Vdc - No Failure 5 Vdc - Failure in T5 or T8 Temperature Control Loop	Failure Indication Monitor
151	0 to 5 Vdc (T6 Temeprature Sensor Analog Output)	
152	0 to 5 Vdc (T9 Temperature Sensor Analog Output)	
153	0 Vdc - No Failure 5 Vdc - Failure in T9 Temperature Control Loop	Failure Indication Monitor
154	0 to 5 Vdc (T7 Temperature Sensor Analog Output)	
155	0 to 5 Vdc (T10 Temperature Sensor Analog Output)	
156	0 Vdc - No Failure 5 Vdc - Failure in T10 Temperature Control Loop	Failure Indication Monitor
157	0 to 5 Vdc (T11 Temperature Sensor Analog Output)	

FLUID CONDITIONING CONTROLS - contd

Monitor Point	Events and Monitor Readout	
158	0 Vdc - No Failure 5 Vdc - Failure in T11 Temperature Control Loop	(Failure Indication Monitor)
159	0 Vdc - T11 Output ENABLE 5 Vdc - Reset T11 Output DISABLE	(Relay Monitor)
160	0 Vdc - SV19-1 OPEN 5 Vdc - SV19-1 CLOSE	Valve Position Switch Monitor (VPSM)
161	0 Vdc - SV19-1 CLOSE 5 Vdc - SV19-1 OPEN	
162	0 Vdc - SV20-1 OPEN 5 Vdc - SV20-1 CLOSE	
163	0 Vdc - SV20-1 CLOSE 5 Vdc - SV20-1 OPEN	
164	0 Vdc - SV23-1 OPEN 5 Vdc - SV23-1 CLOSE	
165	0 Vdc - SV23-1 CLOSE 5 Vdc - SV23-1 OPEN	
166	0 Ved - SV24-1 OPEN 5 Vdc - SV24-1 CLOSE	
167	0 Vdc - SV24-1 CLOSE 5 Vdc - SV24-1 OPEN	
168	0 Vdc - SV19-2 OPEN 5 Vdc - SV19-2 CLOSE	
169	0 Vdc - SV19-2 CLOSE 5 Vdc - SV19-2 OPEN	
170	0 Vdc - SV20-2 OPEN 5 Vdc - SV20-2 CLOSE	
171	0 Vdc - SV20-2 CLOSE 5 Vdc - SV20-2 OPEN	
172	0 Vdc - SV23-2 OPEN 5 Vdc - SV23-2 CLOSE	
173	0 Vdc - SV23-2 CLOSE 5 Vdc - SV23-2 OPEN	

FLUID CONDITIONING CONTROLS - contd

Monitor Point		Events and Monitor Readout
174	0 Vdc - SV24-2 OPEN 5 Vdc - SV24-2 CLOSE	Valve Position Switch Monitor (VPSM)
175	0 Vdc - SV24-2 CLOSE 5 Vdc - SV24-2 OPEN	Valve Position Switch Monitor (VPSM)
176	0 Vdc - SV19-3 OPEN 5 Vdc - SV19-3 CLOSE	Valve Position Switch Monitor (VPSM)
177	0 Vdc - SV19-3 CLOSE 5 Vdc - SV19-3 OPEN	Valve Position Switch Monitor (VPSM)
178	0 Vdc - SV20-3 OPEN 5 Vdc - SV20-3 CLOSE	Valve Position Switch Monitor (VPSM)
179	0 Vdc - SV20-3 CLOSE 5 Vdc - SV20-3 OPEN	Valve Position Switch Monitor (VPSM)
180	0 Vdc - SV23-3 OPEN 5 Vdc - SV23-3 CLOSE	Valve Position Switch Monitor (VPSM)
181	0 Vdc - SV23-3 CLOSE 5 Vdc - SV23-3 OPEN	Valve Position Switch Monitor (VPSM)
182	0 Vdc - SV24-3 OPEN 5 Vdc - SV24-3 CLOSE	Valve Position Switch Monitor (VPSM)
183	0 Vdc - SV24-3 CLOSE 5 Vdc - SV24-3 OPEN	Valve Position Switch Monitor (VPSM)
184	0 Vdc - SV23-4 OPEN 5 Vdc - SV23-4 CLOSE	Valve Position Switch Monitor (VPSM)
185	0 Vdc - SV23-4 CLOSE 5 Vdc - SV23-4 OPEN	Valve Position Switch Monitor (VPSM)
186	0 Vdc - SV24-4 OPEN 5 Vdc - SV24-4 CLOSE	Valve Position Switch Monitor (VPSM)
187	0 Vdc - SV24-4 CLOSE 5 Vdc - SV24-4 OPEN	Valve Position Switch Monitor (VPSM)
188	0 Vdc - T7 Temperature Control ENABLE 5 Vdc - T7 Temperature Control DISABLE	(Relay Monitor)
189	0 Vdc - RESET 5 Vdc - No 2 Control Loop DISABLE	(Relay Monitor)

FLUID CONDITIONING CONTROLS - contd

Monitor Point	Events and Monitor Readout	
190	0 Vdc - SV07-2 CLOSE 5 Vdc - SV07-2 OPEN	Valve Position Switch Monitor (VPSM)
191	0 Vdc - SV07-2 OPEN 5 Vdc - SV07-2 CLOSE	
192	0 Vdc - T5 Temperature Control Loop ENABLE 5 Vdc - T5 Temperature Control Loop DISABLE	(Relay Monitor)
193	0 Vdc - T6 Temperature Control Loop ENABLE 5 Vdc - T6 Temperature Control Loop DISABLE	(Relay Monitor)

LH_2 AND LO_2 TANKS AND PUMPS THERMAL CONDITIONING CONTROLS (FIG. D-6)

Monitor Point	Events and Monitor Readout
194	0 Vdc 5 Vdc (T2 Temperature Sensor Analog Output)
195	0 Vdc 5 Vdc (T1 Temperature Sensor Analog Output)
196	0 Vdc 5 Vdc (T18 Temperature Sensor Analog Output)
197	0 Vdc 5 Vdc (T17 Temperature Sensor Analog Output)
198	0 Vdc 5 Vdc (T16 Temperature Sensor Analog Output)
199	0 Vdc 5 Vdc (T15 Temperature Sensor Analog Output)
200	0 Vdc 5 Vdc (T14 Temperature Sensor Analog Output)
201	0 Vdc 5 Vdc (T13 Temperature Sensor Analog Output)
202	0 Vdc 5 Vdc (T12 Temperature Sensor Analog Output)
203	0 Vdc - Power OFF 5 Vdc - Power ON CF01-1 and -2 Motors
204	0 Vdc - SV16-1 CLOSE 5 Vdc - SV16-1 OPEN
205	0 Vdc - SV16-1 OPEN 5 Vdc - SV16-1 CLOSE
206	0 Vdc - SV16-2 CLOSE 5 Vdc - SV16-2 OPEN
207	0 Vdc - SV16-2 OPEN 5 Vdc - SV16-2 CLOSE
208	0 Vdc - SV16-3 CLOSE 5 Vdc - SV16-3 OPEN
209	0 Vdc - SV16-3 OPEN 5 Vdc - SV16-3 CLOSE

Monitor points 204–209: Valve Position Switch Monitor (VPSM)

LH_2 AND LO_2 TANKS AND PUMPS THERMAL CONDITIONING CONTROLS

Monitor Point		Events and Monitor Readout
210	0 Vdc - SV16-4 CLOSE 5 Vdc - SV16-4 OPEN	Valve Position Switch Monitor (VPSM)
211	0 Vdc - SV16-4 OPEN 5 Vdc - SV16-4 CLOSE	
212	0 Vdc - SV13-4 CLOSE 5 Vdc - SV13-4 OPEN	
213	0 Vdc - SV13-4 OPEN 5 Vdc - SV13-4 CLOSE	
214	0 Vdc - SV13-2 CLOSE 5 Vdc - SV13-2 OPEN	
215	0 Vdc - SV13-2 OPEN 5 Vdc - SV13-2 CLOSE	
216	0 Vdc - SV14-1 CLOSE 5 Vdc - SV14-1 OPEN	
217	0 Vdc - SV14-1 OPEN 5 Vdc - SV14-1 CLOSE	
218	0 Vdc - SV13-3 5 Vdc - SV13-3	
219	0 Vdc - SV13-3 5 Vdc - SV13-3	
220	0 Vdc - SV13-1 5 Vdc - SV13-1	
221	0 Vdc - SV13-1 5 Vdc - SV13-1	
222	0 Vdc - SV14-2 5 Vdc - SV14-2	
223	0 Vdc - SV14-2 5 Vdc - SV14-2	
224	0 Vdc - SV15-1 5 Vdc - SV15-1	
225	0 Vdc - SV15-1 5 Vdc - SV15-1	

LH_2 AND LO_2 TANKS AND PUMPS THERMAL CONDITIONING CONTROLS - contd

Monitor Point		Events and Monitor Readout
226	0 Vdc - SV15-2 5 Vdc - SV15-2	Valve Position Switch Monitor (VPSM)
227	0 Vdc - SV15-2 5 Vdc - SV15-2	
228	0 Vdc - SV15-3 5 Vdc - SV15-3	
229	0 Vdc - SV15-3 5 Vdc - SV15-3	
230	0 Vdc - SV15-4 5 Vdc - SV15-4	
231	0 Vdc - SV15-4 5 Vdc - SV15-4	
232	0 Vdc - SV15-5 5 Vdc - SV15-5	
233	0 Vdc - SV15-5 5 Vdc - SV15-5	
234	0 Vdc - SV15-6 5 Vdc - SV15-6	
235	0 Vdc - SV15-6 5 Vdc - SV15-6	
236	0 Vdc - SV14-3 5 Vdc - SV14-3	
237	0 Vdc - SV14-3 5 Vdc - SV14-3	
238	0 Vdc - Power OFF 5 Vdc - Power ON CF02-1 and -2 Motors	

FAILURE ISOLATION AND CONTROL LOOP SWITCHING (FIG. D-8)

Monitor Point	Events and Monitor Readout	
239	0 Vdc - No Failure 5 Vdc - Failure in No. 1 Loop	(Failure Monitor)
240	0 Vdc - No Failure 5 Vdc - Failure in No. 2 Loop	(Failure Monitor)
241	0 Vdc - No Failure 5 Vdc - Failure in No. 3 Loop	(Failure Monitor)
242	0 Vdc - ENABLE 5 Vdc - DISABLE	(No. 1 Loop Disable Monitor)
243	0 Vdc - ENABLE 5 Vdc - DISABLE	(No. 2 Loop Disable Monitor)
244	0 Vdc - ENABLE 5 Vdc - DISABLE	(No. 3 Loop Disable Monitor)
245	0 Vdc - IV03-1 OPEN 5 Vdc - IV03-1 CLOSE	Valve Position Switch Monitor (VPSM)
246	0 Vdc - IV03-1 CLOSE 5 Vdc - IV03-1 OPEN	
247	0 Vdc - IV03-2 OPEN 5 Vdc - IV03-2 CLOSE	
248	0 Vdc - IV03-2 CLOSE 5 Vdc - IV03-2 OPEN	
249	0 Vdc - IV03-3 OPEN 5 Vdc - IV03-3 CLOSE	
250	0 Vdc - IV03-3 CLOSE 5 Vdc - IV03-3 OPEN	

VENT VALVE CONTROLS (FIG. D-9)

Monitor Point	Events and Monitor Readout	
251	0 Vdc - Low Side 5 Vdc - High Side	(PS03 Pressure Switch Output)
252	0 Vdc - VV02-1 CLOSE 5 Vdc - VV02-1 OPEN	Valve Position Switch Monitor (VPSM)
253	0 Vdc - VV02-1 OPEN 5 Vdc - VV02-1 CLOSE	
254	0 Vdc - VV02-2 CLOSE 5 Vdc - VV02-2 OPEN	
255	0 Vdc - VV02-2 OPEN 5 Vdc - VV0202 CLOSE	
256-260	Same as 251 through 255 Except for VV01	

TYPICAL GAS GENERATOR LEAKAGE FAILURE DETECTION LOGIC (FIG. D-7)

Monitor Point	Events and Monitor Readout	
261	0 Vdc 5 Vdc	(LD01 Output)
262	0 Vdc - ENABLE 5 Vdc - DISABLE	(LD01 Enable/Disable Relay Monitor)
263	0 Vdc - IV05-1 OPEN 5 Vdc - IV05-1 CLOSE	Valve Position Switch Monitor (VPSM)
264	0 Vdc - IV05-1 CLOSE 5 Vdc - IV05-1 OPEN	
265	0 Vdc - IV05-2 OPEN 5 Vdc - IV05-2 CLOSE	
266	0 Vdc - IV05-2 CLOSE 5 Vdc - IV05-2 OPEN	
267-272	Same as 261 through 266 Except for LD01-2	
273-278	Same as 261 through 266 Except for LD01-3	
279-284	Same as 261 through 266 Except for LD01-4	
285-290	Same as 261 through 266 Except for LD01-5	
291-296	Same as 261 through 266 Except for LD01-6	
297-302	Same as 261 through 266 Except for LD01-7	
303-308	Same as 261 through 266 Except for LD01-8	
309-314	Same as 261 through 266 Except for LD01-9	
315-320	Same as 261 through 266 Except for LD01-10	
321-326	Same as 261 through 266 Except for LD01-11	
327-332	Same as 261 through 266 Except for LD01-12	
333-338	Same as 261 through 266 Except for LD01-13	
339-344	Same as 261 through 266 Except for LD01-14	

FILL VALVE CONTROLS

Monitor Point	Events and Monitor Readout
345	Start Relay Monitor 5 Vdc - Fill off 0 Vdc - Start fill
346	LL02 LH_2 Tank Level Sensor 0 to 5 Vdc
347	VPSM 5 Vdc - FV01-1 OPEN 0 Vdc - FV01-1 CLOSED
348	VPSM 5 Vdc - FV01-1 CLOSED 0 Vdc - FV01-1 OPEN
349	LL02 Sensor Output Relay Monitor 5 Vdc - $<$ max liquid level 0 Vdc - $>$ max liquid level
350	VPSM 5 Vdc - FV01-2 OPEN 0 Vdc - FV01-2 CLOSED
351	VPSM 5 Vdc - FV01-2 CLOSED 0 Vdc - FV01-2 OPEN
352	VPSM 5 Vdc - FV01-3 OPEN 0 Vdc - FV01-3 CLOSED
353	VPSM 5 Vdc - FV01-3 CLOSED 0 Vdc - FV01-3 OPEN
354	VPSM 5 Vdc - FV01-4 OPEN 0 Vdc - FV01-4 CLOSED
355	VPSM 5 Vdc - FV01-4 CLOSED 0 Vdc - FV01-4 OPEN

D.2 SUBCRITICAL AUXILIARY POWER UNIT SUPPLY

The functional schematic for the APU supply is presented in Figure D-13. The following results provide the necessary data:

Figure D-14	GH_2 Accumulator Pressure Controls
Figure D-15	LH_2 Tank - Helium Pressurization Controls
Figure D-16	Heat Exchanger Temperature Control - Pump Outlet, GH_2 Side
Figure D-17	Heat Exchanger Temperature Control - Accumulator Outlet, GH_2 Side
Figure D-18	GH_2 Pressure Regulation Control - Accumulator Outlet
Figure D-19	LH_2 and LO_2 Tanks - Thermal Conditioning Controls
Figure D-20	Vent Valve Control - LO_2 Tank
Figure D-21	Fill Valve Control
Figure D-22	Event Flow Chart
Figure D-23	Controls Block Diagram
Table D-2	Instrumentation and Controls Monitor List

The typical control loops described herein are ON-OFF and open loop; consisting of a sensor, sensor output electronics, failure detection/isolation circuitry and a fluid control actuator.

All sensors (P5-2, T4-2, PS01, etc.) actually consist of four (4) identical sensing elements plus associated failure detection and isolation circuitry - to assure proper sensing information in the event of one (1) or two (2) individual sensor malfunctions.

Figure D-23 illustrates the redundancy provided by the controls subsystem to meet the fail operational/fail operational design criteria. Each control loop consists of three (3) sub-loops. System operation commences by starting the No. 1 sub-loop in each case. Any subsequent failures of malfunctions will sequentially enable/disable the sub-loops involved for up to two (2) failures per control function. There could be two (2) failures in each of the seven (7) functional control loops and the system operating requirements would still be met.

These results apply to any orbiter with a cryogenic APU.

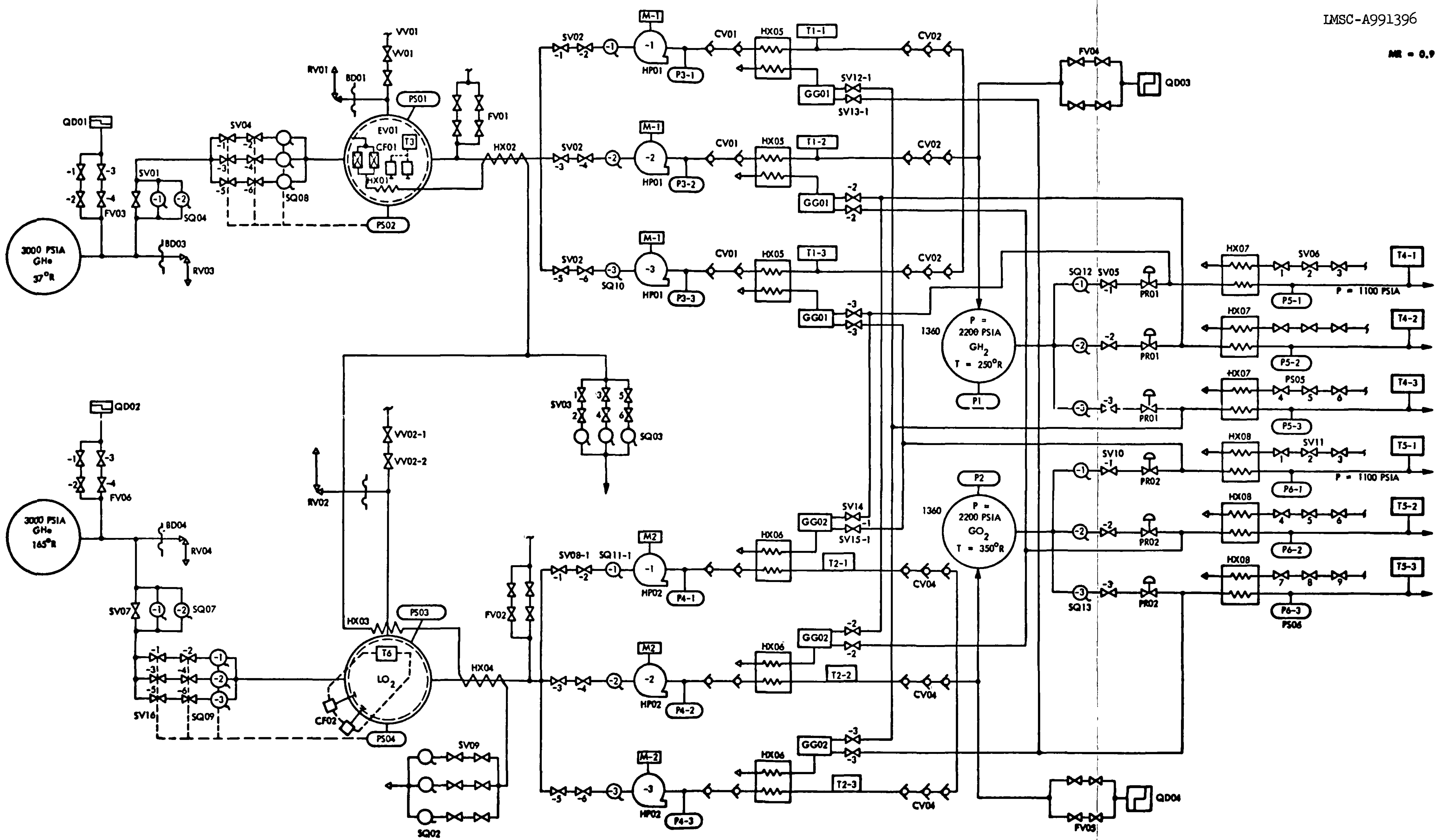

Fig. D-13 Supercritical APU Cryogenic Supply Subsystem

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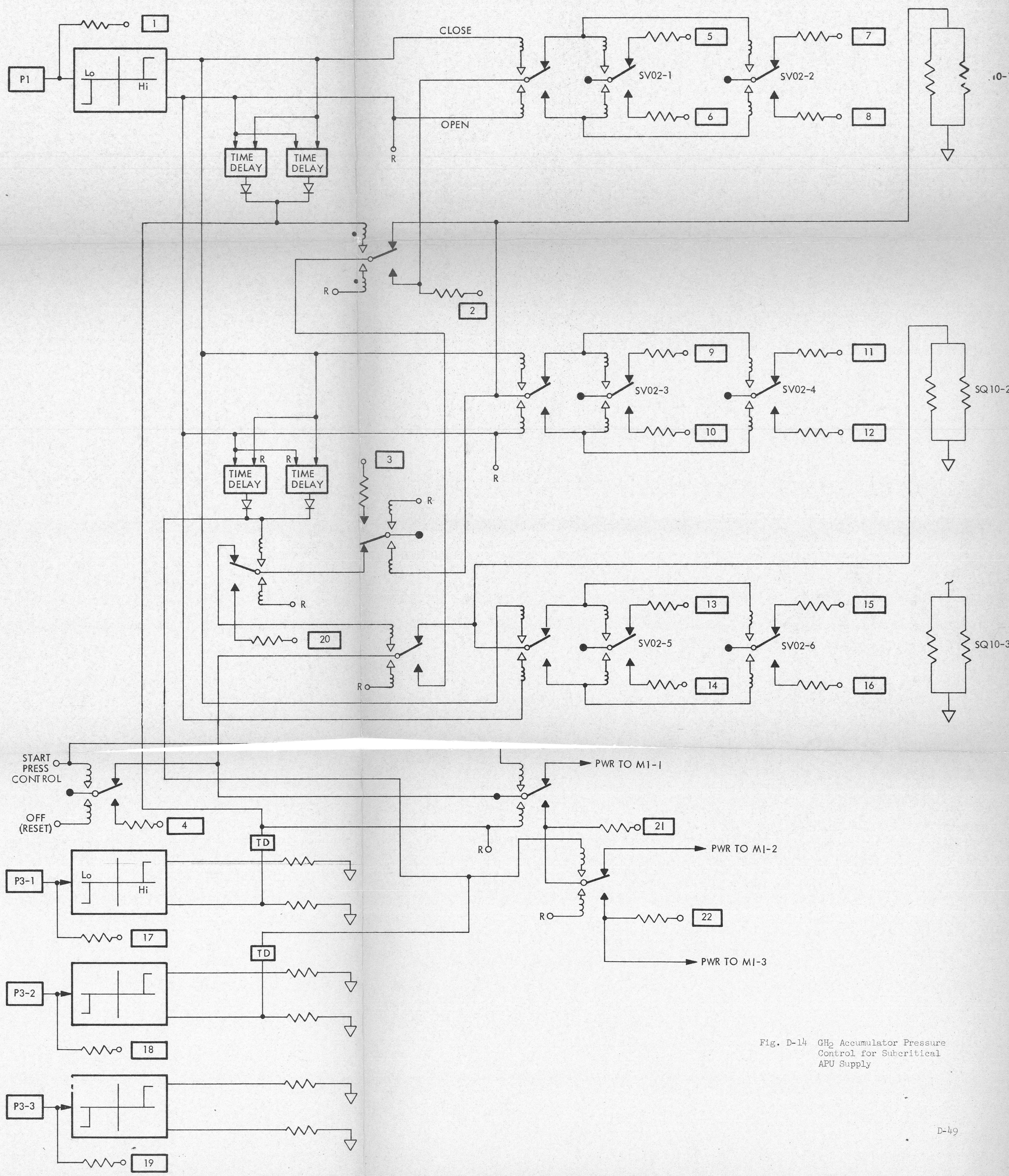

Fig. D-14 GH_2 Accumulator Pressure Control for Subcritical APU Supply

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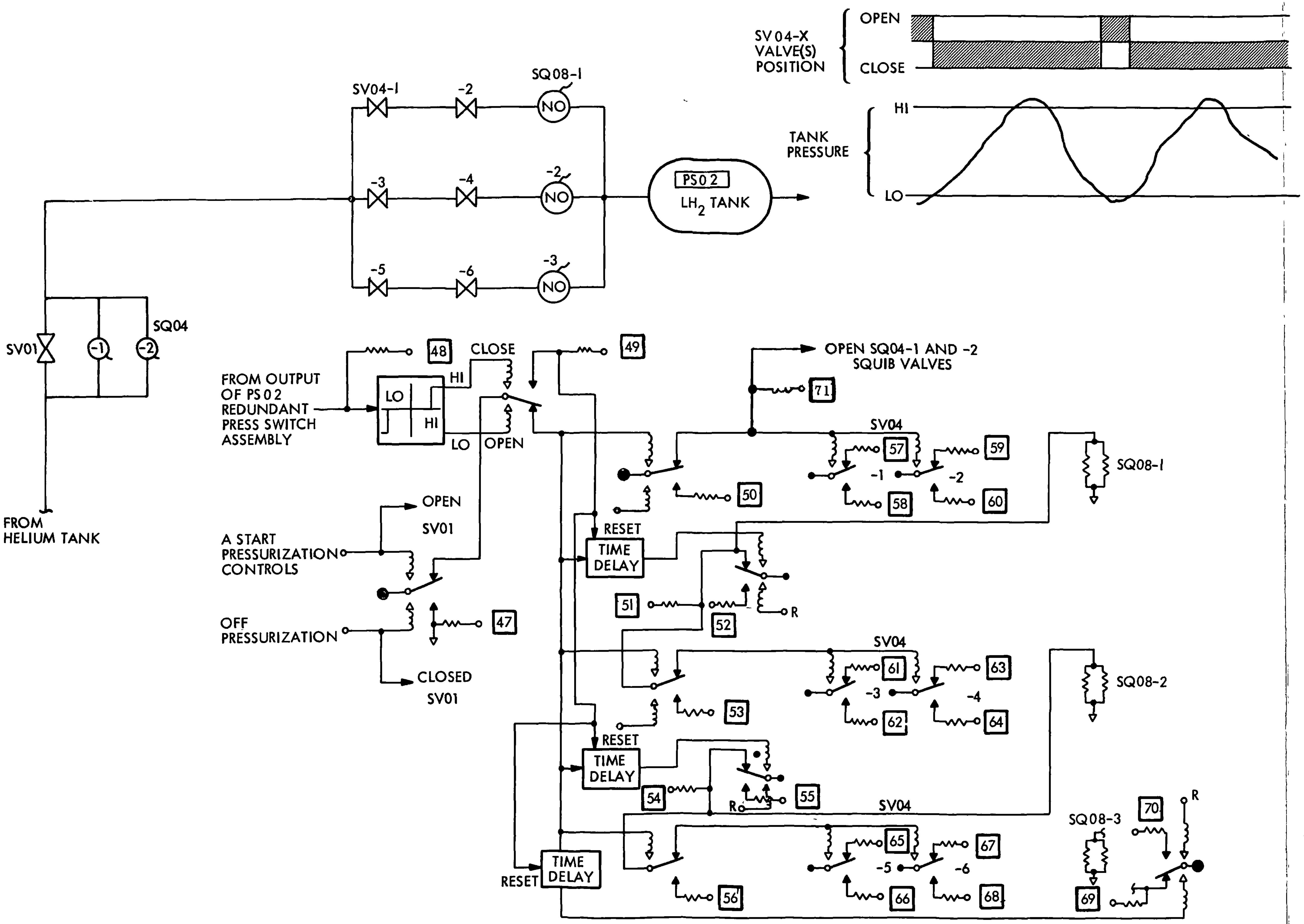

ASSUMPTIONS

1. ACCEPTANCE TESTING COMPLETED. ALL VALVES OPERATING PROPERLY AND NO LEAKAGE IN SYSTEM.
2. SV04 CONTROL VALVES ARE NORMALLY CLOSED SOLENOID OPERATED VALVES. THESE VALVES OPEN WHEN POWER IS APPLIED AND CLOSE WHEN POWER IS REMOVED.
3. THE SQ08 VALVES ARE NORMALLY OPEN, SQUIB-ACTUATED VALVES.

~~ON-OFF PRESSURIZATION CONTROLS - THE CONTROL LOOP CONSISTS OF A QUAD-REDUNDANT~~ PRESSURE LIMIT SWITCH, (3) SETS OF ON/OFF VALVING, AND ASSOCIATED LOGIC AND CONTROL ELECTRONICS.

THE OUTPUT OF THE PRESSURE SWITCH ENERGIZES A NORMALLY OPEN RELAY WHICH CLOSES AND SENDS AN "OPEN" SIGNAL TO THE FIRST SET OF CONTROL VALVES (SV04-1 AND -2). THIS COMMAND IS ALSO SENT TO THE DRIVING RELAY FOR SV04-3 AND -4, AND SV04-5 AND -6, BUT POWER TO THESE RELAYS IS LOCKED OUT UNTIL A FAILURE OCCURS IN THE PREVIOUS SET OF CONTROL VALVES.

A SIGNAL IS ALSO SENT TO A TIME DELAY CIRCUIT SIMULTANEOUS WITH THE SV04 "OPEN" SIGNAL. IF THE PRESSURE DOES NOT INCREASE ABOVE THE PRESSURE SETTING OF THE LIMIT SWITCH IN A CERTAIN PERIOD OF TIME (BASED ON NOMINAL RESPONSE TIME OF SYSTEM) INDICATING VALVE(S) MALFUNCTION -- THE TIME DELAY CIRCUIT WILL DEACTIVATE THE FIRST SET OF CONTROL VALVES BY ACTUATING SQ08-1 CLOSED AND ACTIVATING THE SECOND SET OF CONTROL VALVES (SV04-3 AND -4).

THIS PROCESS IS REPEATED FOR A MALFUNCTION OF SV04-3 AND -4, IN WHICH CASE SQ08-2 IS CLOSED AND SV04-5 AND -6 ARE ACTIVATED.

Fig. D-15 LH_2 Tank Helium Pressurization Controls

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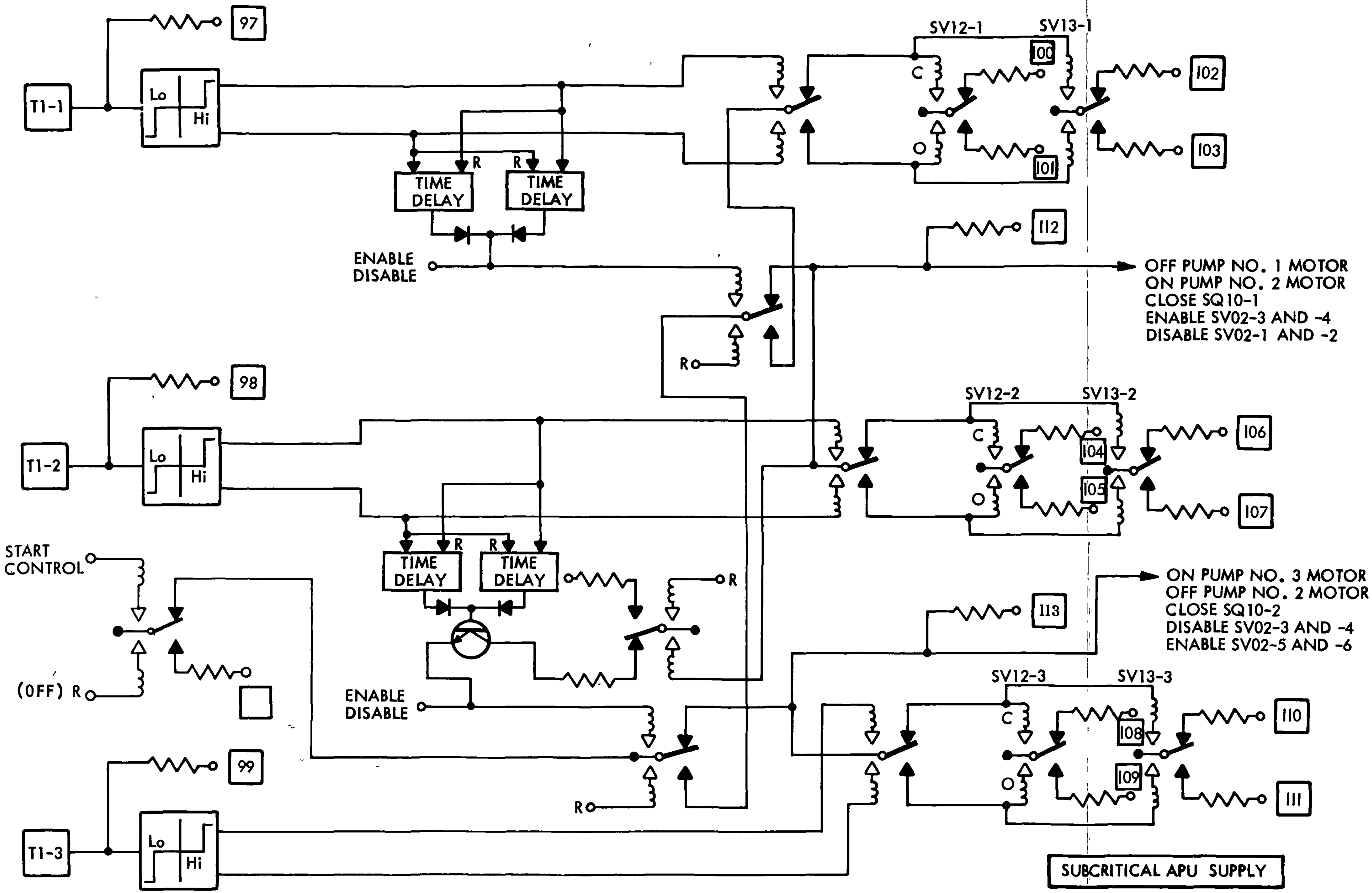

Fig. D-16 Heat Exchanger Temperature Controls (Pump Outlet), H_2 Side

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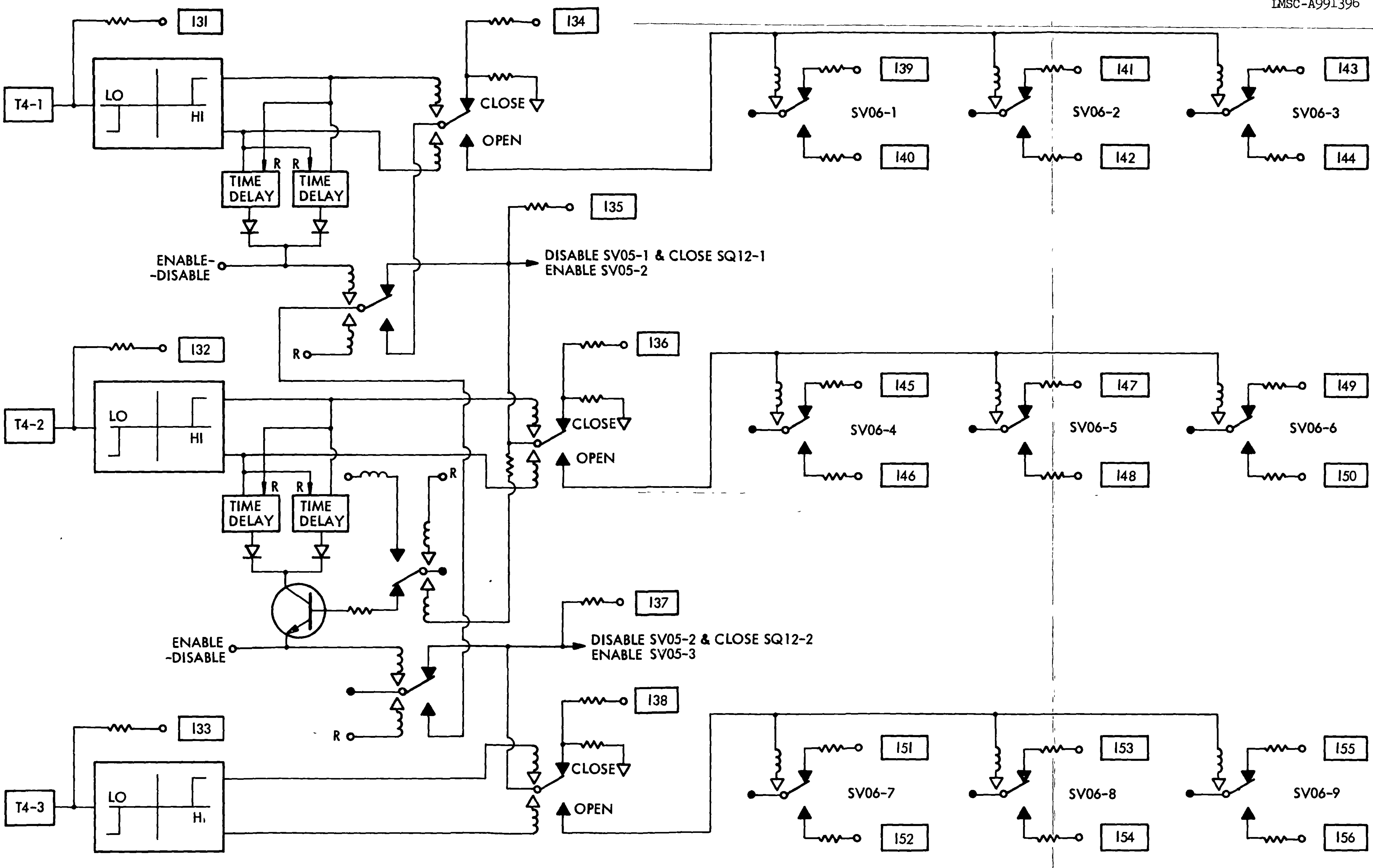

Fig. D-17 Heat Exchanger Temperature Controls (Accumulator Outlet - GH_2 Side)

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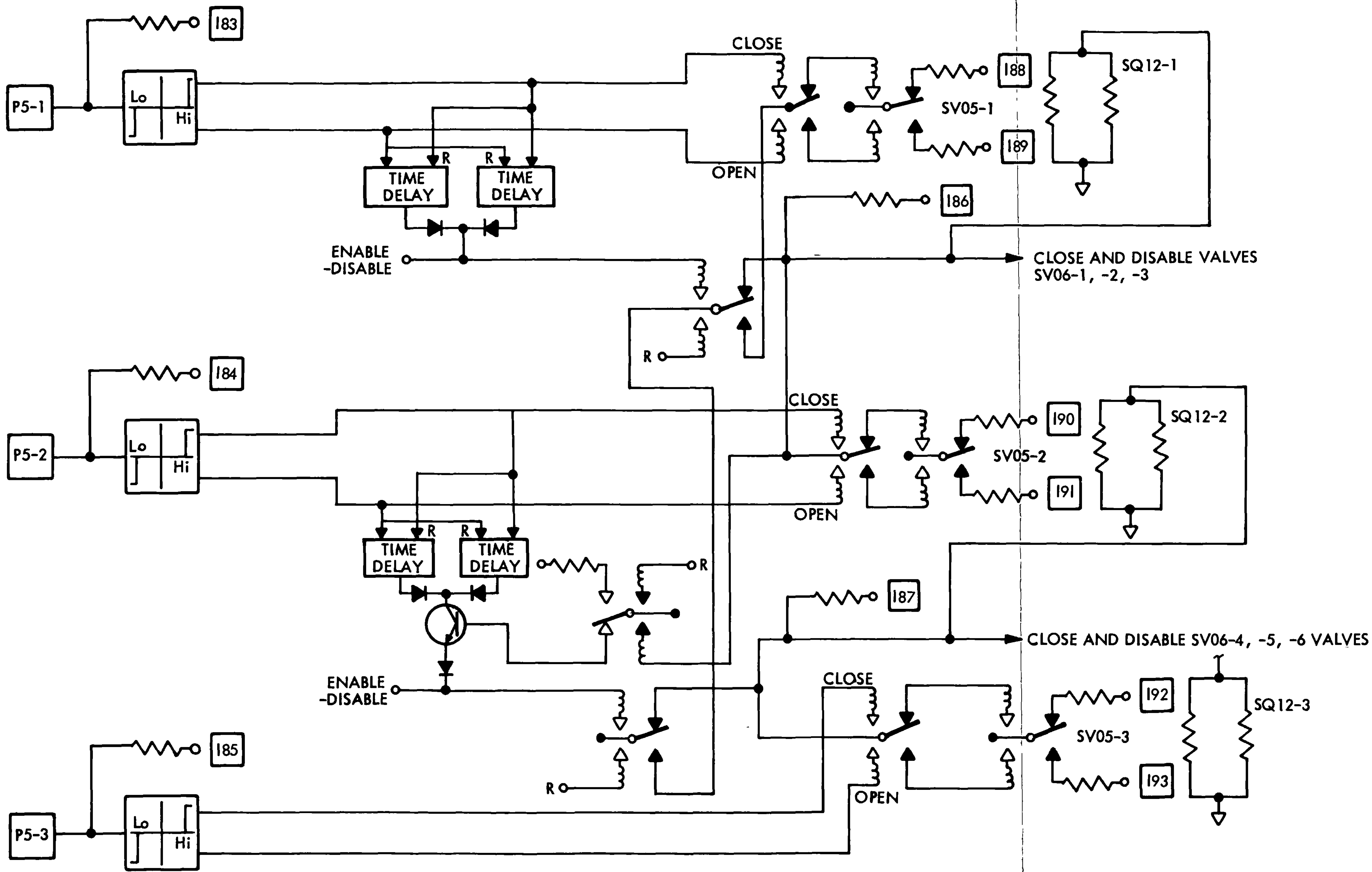

Fig. D-18 GH_2 Pressure Regulation Control - Accumulator Outlet

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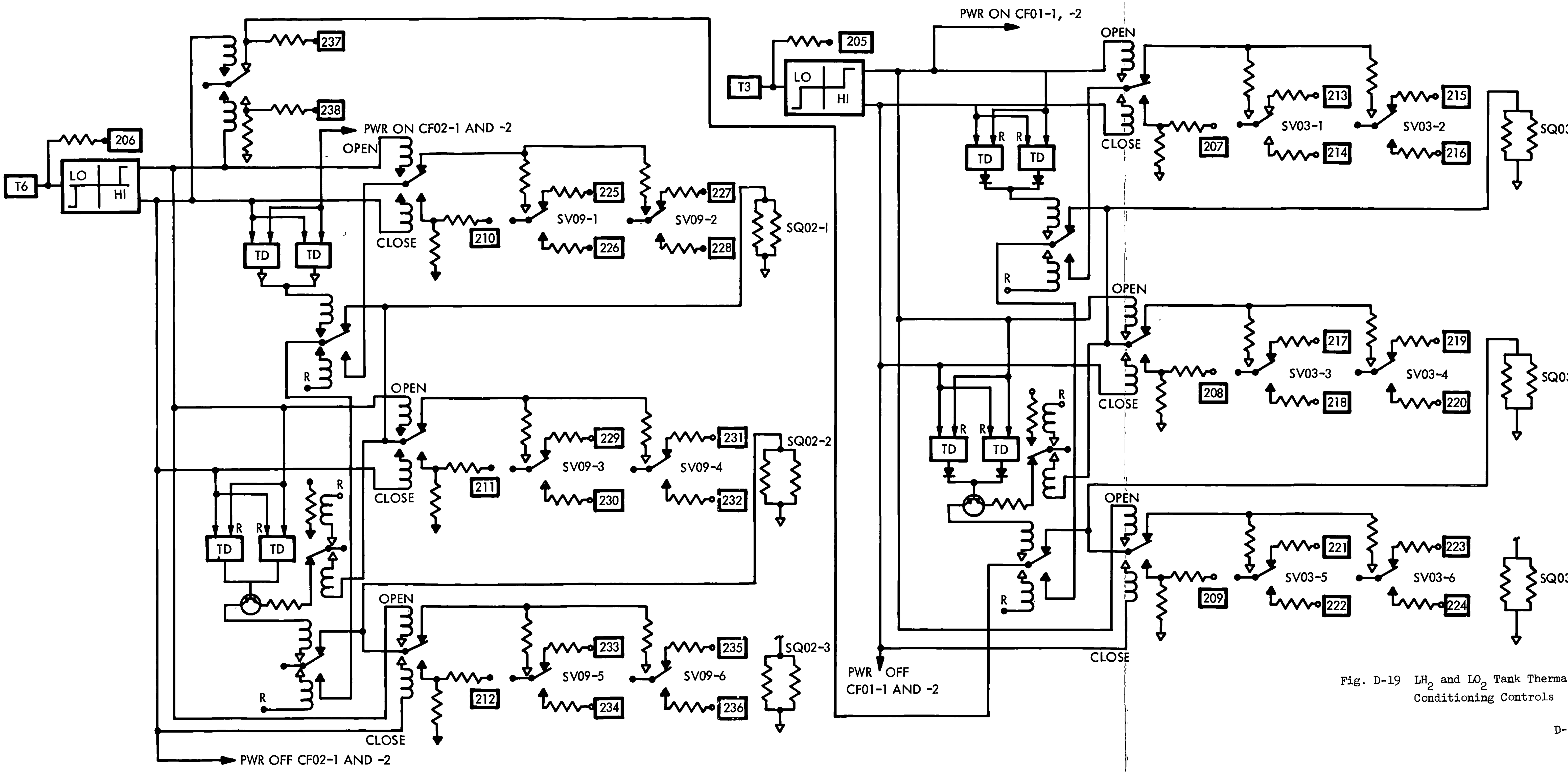

Fig. D-19 LH_2 and LO_2 Tank Thermal Conditioning Controls

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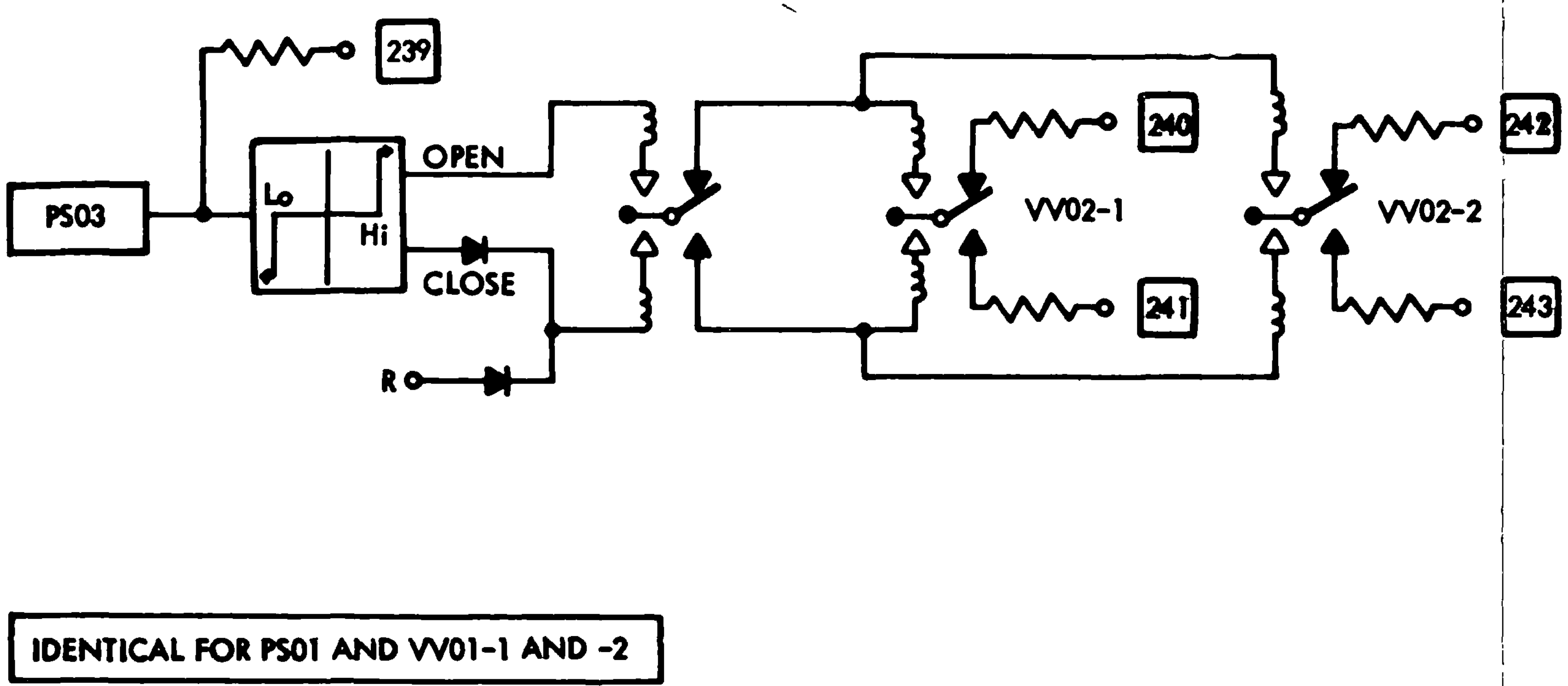

Fig. D-20 Vent Valve Control and Monitoring Points - LO_2 Tank

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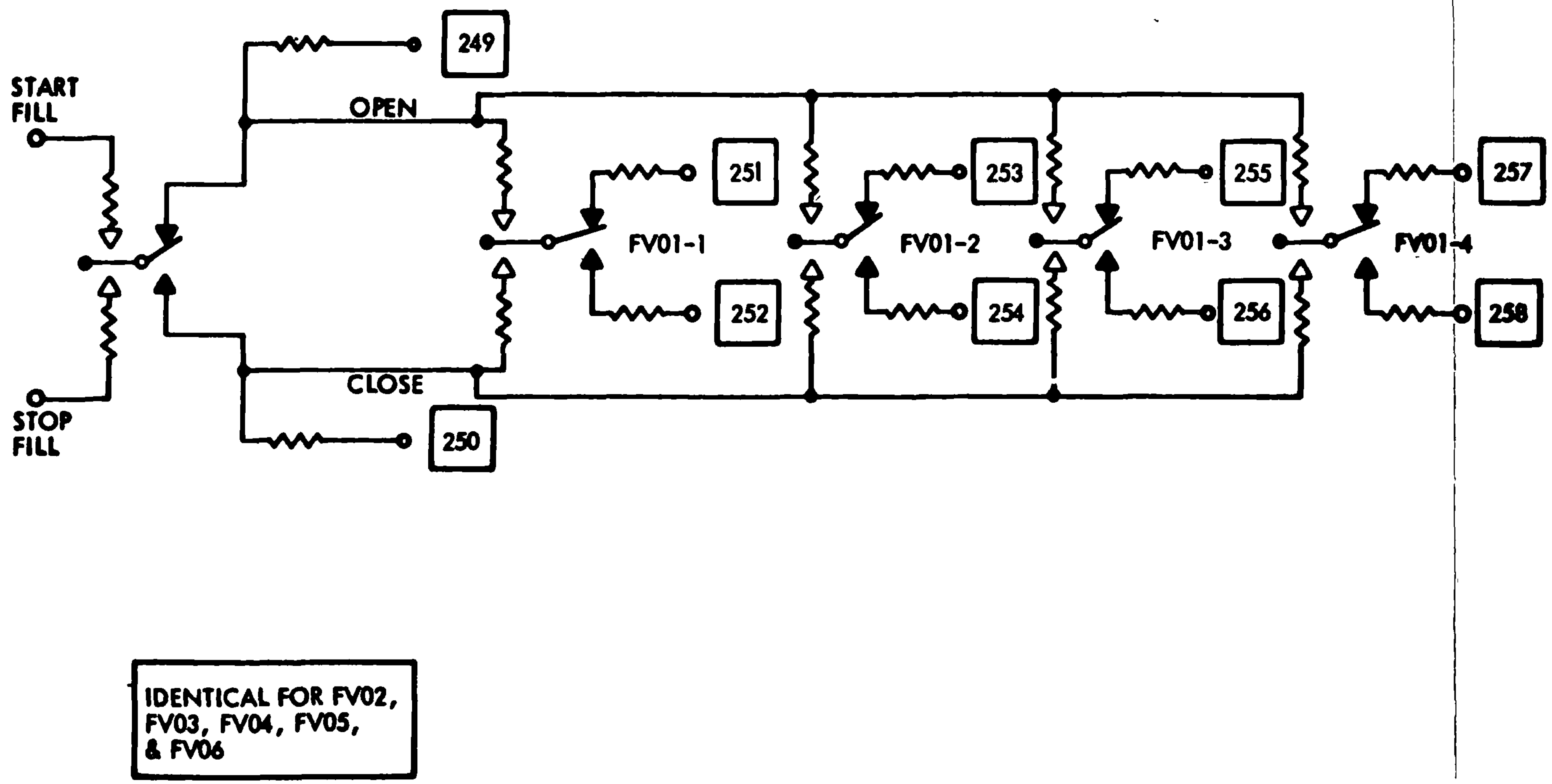

Fig. D-21 Fill Valves Control and Monitoring Points

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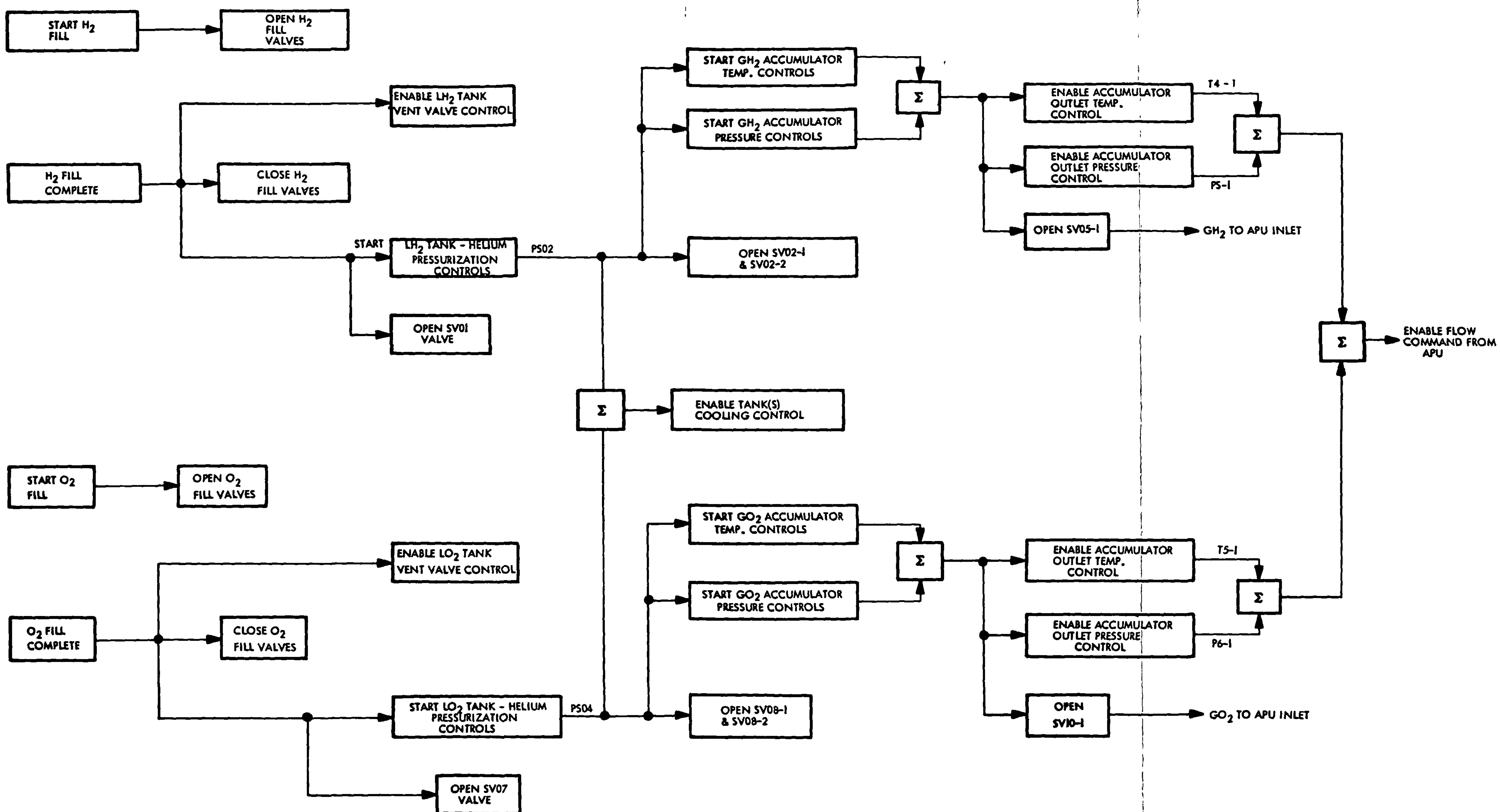

Fig. D-22 Event Flow Chart for Subcritical APU Supply

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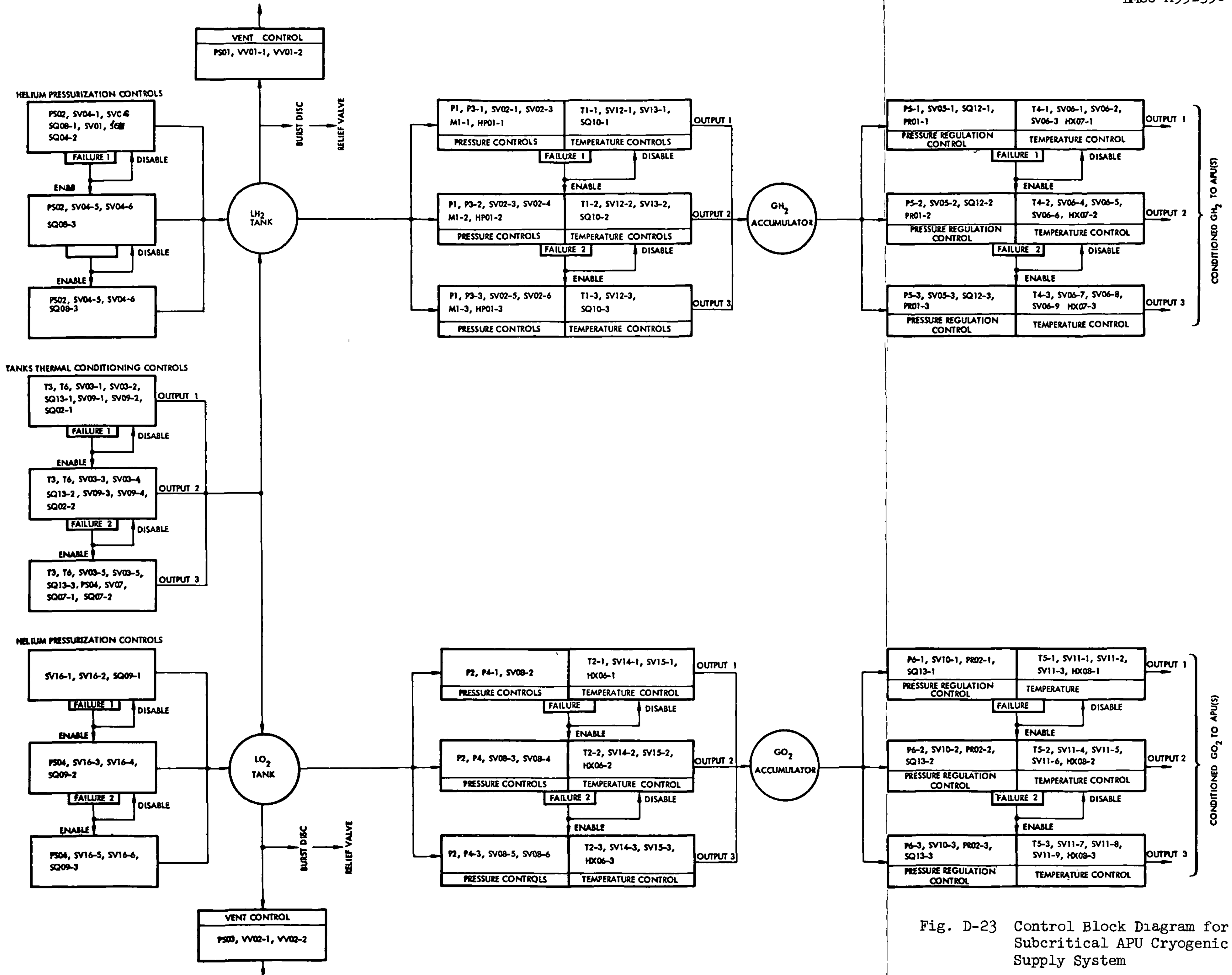

Fig. D-23 Control Block Diagram for Subcritical APU Cryogenic Supply System

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Table D-2

INSTRUMENTATION AND CONTROLS MONITOR LIST

GH_2 ACCUMULATOR PRESSURE CONTROLS (FIG. D-14)

Monitor Point	
1	P1 Pressure Transducer Output 0 to 5 Vdc
2	Relay Monitor 0 or 5 Vdc 5 Vdc - Reset position, power to No. 1 control loop 0 Vdc - Power to No. 2 control loop, disable No. 1 control loop
3	Relay Monitor 0 to 5 Vdc 5 Vdc - Reset position 0 Vdc - Enable No. 3 control loop
4	System Start Relay 0 or 5 Vdc 5 Vdc - Reset position (off pressurization control) 0 Vdc - Start pressurization control
5	Valve Position Monitor 0 or 5 Vdc 5 Vdc - SV02-1 open 0 Vdc - SV02-1 closed
6	Valve Position Monitor 0 or 5 Vdc 5 Vdc - SV02-1 closed 0 Vdc - SV02-1 open
7 & 8	Same as 5 and 7 except for SV02-2
9 & 10	Same as 5 and 6 except for SV02-3
11 & 12	Same as 5 and 6 except for SV02-4
13 & 14	Same as 5 and 6 except for SV02-5
15 & 16	Same as 5 and 6 except for SV02-6
17	P3-1 Pressure Transducer Output 0 to 5 Vdc
18	P3-2 Pressure Transducer Output 0 to 5 Vdc
19	P3-3 Pressure Transducer Output 0 to 5 Vdc
20	Relay Monitor 0 or 5 Vdc 5 Vdc - Reset Position 0 Vdc - Power to No. 3 control loop Disable No. 2 control loop

Monitor Point	
21	Relay Monitor 0 or 5 Vdc 5 Vdc - Power off M1 motor 0 Vdc - Power on M1 motor
22	Same as 21 except for M2
23	Same as 21 except for M3
24 through 46	Same as 1 through 23 except for GO_2 side

LH_2 TANK HELIUM PRESSURIZATION CONTROLS (FIG. D-15)

Monitor Point	
47	Start Relay Monitor 0 or 5 Vdc 5 Vdc - Off pressurization, SV01 closed 0 Vdc - Start pressurization, SV01 open
48	PS02 Pressure Switch Monitor 0 or 5 Vdc 5 Vdc - Hi limit 0 Vdc - Lo limit
49	Relay Monitor 1 or 5 Vdc 5 Vdc - Hi limit 0 Vdc - Lo limit
50	Relay Monitor 0 or 5 Vdc 5 Vdc - Reset position 0 Vdc - Command open SV04-1 and -2
51	Relay Monitor 0 or 5 Vdc 5 Vdc - Disable No. 1 control loop valves 0 Vdc - Reset position
52	Relay Monitor 0 or 5 Vdc 5 Vdc - Reset position 0 Vdc - Enable No. 2 control loop valves
53	Relay Monitor 0 or 5 Vdc 5 Vdc - Power OFF SV04-3 and -4 (closed) 0 Vdc - Power ON SV04-3 and -4 (open)
54	Relay Monitor 0 or 5 Vdc 5 Vdc - Enable No. 3 control loop valves 0 Vdc - Disable No. 2 control loop valves
55	Relay Monitor 0 or 5 Vdc 5 Vdc - Reset 0 Vdc - Enable No. 3 control loop valves
56	Relay Monitor 0 or 5 Vdc 5 Vdc - Reset (power OFF SV04-5 and -6 valves) 0 Vdc - Power to SV04-5 and -6 valves

Monitor Point	
57	Valve Position Monitor 0 or 5 Vdc 5 Vdc - SV04-1 open 0 Vdc - SV04-2 closed
58	Valve Position Monitor 0 or 5 Vdc 5 Vdc - SV04-1 closed 0 Vdc - SV04-1 open
59 & 60	Same as 31 and 32 except for SV04-2
61 & 62	Same as 31 and 32 except for SV04-3
63 & 64	Same as 31 and 32 except for SV04-4
65 & 66	Same as 31 and 32 except for SV04-5
67 & 68	Same as 31 and 32 except for SV04-6
69	Relay Monitor 0 or 5 Vdc 0 Vdc - Reset 5 Vdc - Output from time delay circuit
70	Relay Monitor 0 or 5 Vdc 5 Vdc - Reset 0 Vdc - Output from time delay circuit
71	Relay Monitor 5 Vdc - Power to SQ04-1 and -2 0 Vdc - Power OFF
72 through 96	Same as 47 through 71 except for LO_2 side

HEAT EXCHANGER TEMPERATURE CONTROLS (H_2 SIDE PUMP OUTPUT) - FIG. D-16

Monitor Point	
97	T1-1 Temperature Transducer Output 0 to 5 Vdc
98	T1-2 Temperature Transducer Output 0 to 5 Vdc
99	T1-3 Temperature Transducer Output 0 to 5 Vdc
100	SV12-1 Position Indicator 0 or 5 Vdc 5 Vdc - Valve closed 0 Vdc - Valve open
101	SV12-1 Position Indicator 0 or 5 Vdc 5 Vdc - Valve open 0 Vdc - Valve closed
102 & 103	Same as 54 and 55 except for SV13-1
104 & 105	Same as 54 and 55 except for SV12-2
106 & 107	Same as 54 and 55 except for SV13-2
107 & 109	Same as 54 and 55 except for SV12-3
110 & 111	Same as 54 and 55 except for SV13-3
112	Relay Monitor 0 or 5 Vdc 5 Vdc - Enable SV12-2 and SV13-2 0 Vdc - Reset
113	Relay Monitor 0 or 5 Vdc 5 Vdc - Enable SV12-3 and SV13-3 Disable SV12-2 and SV13-2
114 through 130	Same as 97 through 113 except for O_2 side

HEAT EXCHANGER TEMPERATURE CONTROLS - ACCUMULATOR OUTLET (H_2 SIDE) - FIG. D-17

Monitor Point	
131	T4-1 Temperature Transducer Output 0 to 5 Vdc
132	T4-2 Temperature Transducer Output 0 to 5 Vdc
133	T4-3 Temperature Transducer Output 0 to 5 Vdc
134	Relay Monitor 0 to 5 Vdc 5 Vdc - Remove power (close) from SV06-1, -2, -3 0 Vdc - Power ON (open) SV06-1, -2, -3
135	Relay Monitor 0 or 5 Vdc 5 Vdc - Disable SV06-1, -2, -3 Enable SV06-4, -5, -6 0 Vdc - Reset
136	Relay Monitor 0 or 5 Vdc 5 Vdc - Power OFF (close) SV06-4, -5, -6 0 Vdc - Power ON (open) SV06-4, -5, -6
137	Relay Monitor 0 or 5 Vdc 5 Vdc - Disable SV02, close SQ12-2, enable SV05-3 0 Vdc - Reset
138	Relay Monitor 0 or 5 Vdc 5 Vdc - Power OFF (close) SV06-7, -8, -9 0 Vdc - Power ON (open) SV06-7, -8, -9
139	Valve Position Indicator Switch Monitor 0 or 5 Vdc 5 Vdc - SV06-1 open 0 Vdc - SV06-1 close
140	Valve Position Indicator Switch Monitor 0 or 5 Vdc 5 Vdc - SV06-1 close 0 Vdc - SV06-1 open
141 & 142	Same as 139 and 140 except for SV06-2
143 & 144	Same as 139 and 140 except for SV06-3
145 & 146	Same as 139 and 140 except for SV06-4
147 & 148	Same as 139 and 140 except for SV06-5

Monitor Point	
149 & 150	Same as 139 and 140 except for SV06-6
151 & 152	Same as 139 and 140 except for SV06-7
153 & 154	Same as 139 and 140 except for SV06-8
155 & 156	Same as 139 and 140 except for SV06-9
157 through 182	Same as 131 through 156 except for O_2 side

GH_2 PRESSURE REGULATION CONTROL - ACCUMULATOR OUTLET (H_2 SIDE) - FIG. D-18

Monitor Point	
183	P5-1 Pressure Transducer Output 0 to 5 Vdc
184	P5-2 Pressure Transducer Output 0 to 5 Vdc
185	P5-3 Pressure Transducer Output 0 to 5 Vdc
186	Relay Monitor 0 or 5 Vdc
187	Relay Monitor 0 or 5 Vdc 5 Vdc - Close and disable SV06-4, -5, -6 valves 0 Vdc - Reset
188	Valve Position Indicator Switch Monitor 0 or 5 Vdc 5 Vdc - SV05-1 close 0 Vdc - SV05-1 open
189	Valve Position Indicator Switch Monitor 0 or 5 Vdc 5 Vdc - SV05-1 open 0 Vdc - SV05-1 close
190 & 191	Same as 101 and 102 except for SV05-2
192 & 193	Same as 101 and 102 except for SV05-3
194 through 204	Same as 183 through 193 except for O_2 side

LH_2 AND LO_2 TANK COOLING CONTROLS - FIG. D-19

Monitor Point	
205	T3 Temperature Sensor Output 0 to 5 Vdc
206	T6 Temperature Sensor Output 0 to 5 Vdc
207	Relay Monitor 0 to 5 Vdc 5 Vdc - Power OFF (close) SV03-1 and -2 0 Vdc - Power ON (open) SV03-1 and -2
208	Relay Monitor 0 or 5 Vdc 5 Vdc - Power OFF (close) SV03-3 and -4 0 Vdc - Power ON (open) SV03-3 and -4
209	Relay Monitor 0 or 5 Vdc 5 Vdc - Power OFF (close) SV03-5 and -6 0 Vdc - Power ON (open) SV03-5 and -6
210	Relay Monitor 0 or 5 Vdc 5 Vdc - Power OFF (close) SV09-1 and -2 0 Vdc - Power ON (open) SV09-1 and -2
211	Relay Monitor 0 or 5 Vdc 5 Vdc - Power OFF (close) SV09-3 and -4 0 Vdc - Power ON (open) SV09-3 and -4
212	Relay Monitor 0 or 5 Vdc 5 Vdc - Power OFF (close) SV09-5 and -6 0 Vdc - Power ON (open) SV09-5 and -6
213	Valve Position Indicator Switch 0 or 5 Vdc 5 Vdc - SV03-1 open 0 Vdc - SV03-1 close
214	Valve Position Indicator Switch 0 or 5 Vdc 5 Vdc - SV03-1 close 0 Vdc - SV03-1 open
215 & 216	Same as 213 and 214 except for SV03-2
217 & 218	Same as 213 and 214 except for SV03-3
219 & 220	Same as 213 and 214 except for SV03-4

Monitor Point	
221 & 222	Same as 213 and 214 except for SV03-5
223 & 224	Same as 213 and 214 except for SV03-6
225 & 226	Same as 213 and 214 except for SV09-1
227 & 228	Same as 213 and 214 except for SV09-2
229 & 230	Same as 213 and 214 except for SV09-3
231 & 232	Same as 213 and 214 except for SV09-4
233 & 234	Same as 213 and 214 except for SV09-5
235 & 236	Same as 213 and 214 except for SV09-6
237	T7 Priority Relay Monitor 0 or 5 Vdc 5 Vdc - Power to T3 control loop (enabled) 0 Vdc - Power OFF T3 control loop (disabled)
238	T6 Priority Relay Monitor 0 or 5 Vdc 5 Vdc - Power OFF T3 control loop 0 Vdc - Power to T3 control loop

VENT VALVE CONTROL - LO_2 TANK, FIG. D-20

Monitor Point	
239	Valve Position Indicator Switch Monitor 0 or 5 Vdc 5 Vdc - open (VV02-1) 0 Vdc - closed (VV02-1)
240	Valve Position Indicator Switch Monitor 0 or 5 Vdc 5 Vdc - closed (VV02-1) 0 Vdc - open (VV02-1)
241 & 242	Same as 231 and 232 except for VV02
243	Output of PS03 Pressure Switch 1 or 5 Vdc 1 Vdc - Low limit 5 Vdc - Hi limit
244 through 248	Same as 239 through 243 except for LH_2 tank

FV01 FILL VALVE CONTROL AND MONITORS (FIG. D-21)

Monitor Point	
249	Start Relay Monitor 0 or 5 Vdc 5 Vdc - Start fill 0 Vdc - Stop fill
250	Start Relay Monitor 0 or 5 Vdc 5 Vdc - Stop fill 0 Vdc - Start fill
251	Valve Position Indicator Switch Monitor 0 or 5 Vdc 5 Vdc - Open 0 Vdc - Closed
252	Valve Position Indicator Switch Monitor 0 or 5 Vdc 5 Vdc - Closed (FV01) 0 Vdc - Open (FV01)
253 & 254	Same as 251 and 252 except for FV01-2
255 & 256	Same as 251 and 252 except for FV01-3
257 & 258	Same as 251 and 252 except for FV01-4
259 through 268	Same as 249 through 258 except for FV02
269 through 278	Same as 249 through 258 except for FV03
279 through 288	Same as 249 through 258 except for FV04
289 through 298	Same as 249 through 258 except for FV05
299 through 308	Same as 249 through 258 except for FV06

D.3 INTEGRATED FUEL CELL/LIFE SUPPORT SUPPLY

The Integrated Fuel Cell/Life Support Supply utilizes supercritical storage. The functional schematic for the FC/LSS is presented in Figure D-27.

The typical control loops described herein are open-loop, ON-OFF; consisting of a sensor, sensor output electronics, failure detection/isolation circuitry and a fluid control actuator.

All sensors indicated on the control schematics (PT01, CS05, TT04, etc.) actually consist of four (4) identical sensing elements plus associated failure detection and isolation circuitry - to assure proper sensing information in the event of one (1) or two (2) individual sensor malfunctions.

The following figures illustrate in block diagram form the fail operational/fail operational control loop design configurations selected:

Figure D-24	O_2 and N_2 Controls - Cabin Pressurization and H_2O Tank Pressurization
Figure D-25	O_2 Fluid Conditioning Controls
Figure D-26	H_2 Fluid Conditioning Controls

The instrumentation and control systems resulting from the evaluations are:

Figure D-28	O_2 and N_2 Controls Schematic - Cabin Pressurization and H_2O Tank Pressurization
Figure D-29	O_2 Fluid Conditioning Controls Schematic
Figure D-30	H_2 Fluid Conditioning Controls Schematic
Figure D-31	Event Flow Chart
Table D-3	Instrumentation and Controls Monitor List

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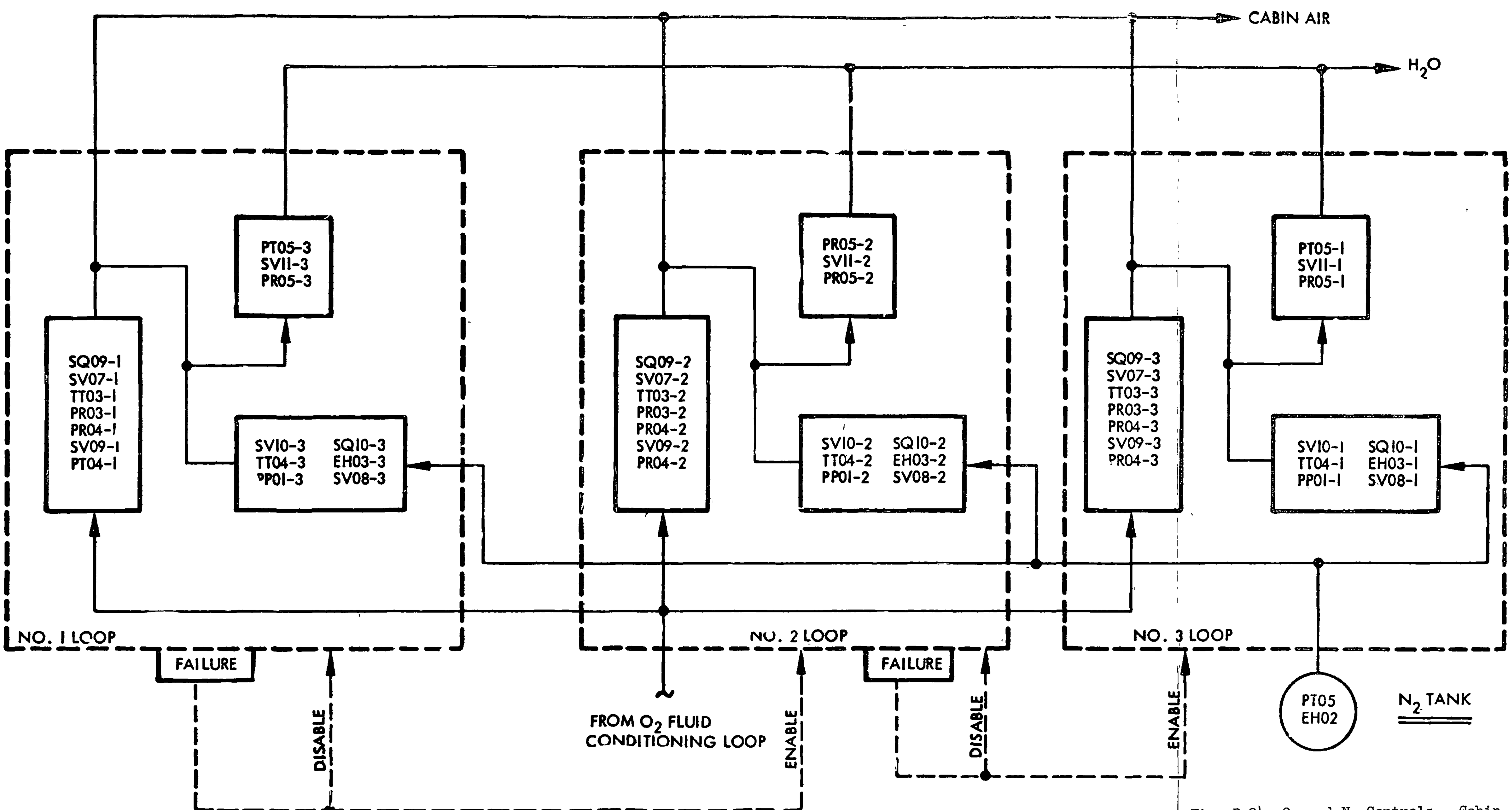

Fig. D-24 O_2 and N_2 Controls - Cabin Pressurization and H_2O Tank Pressurization

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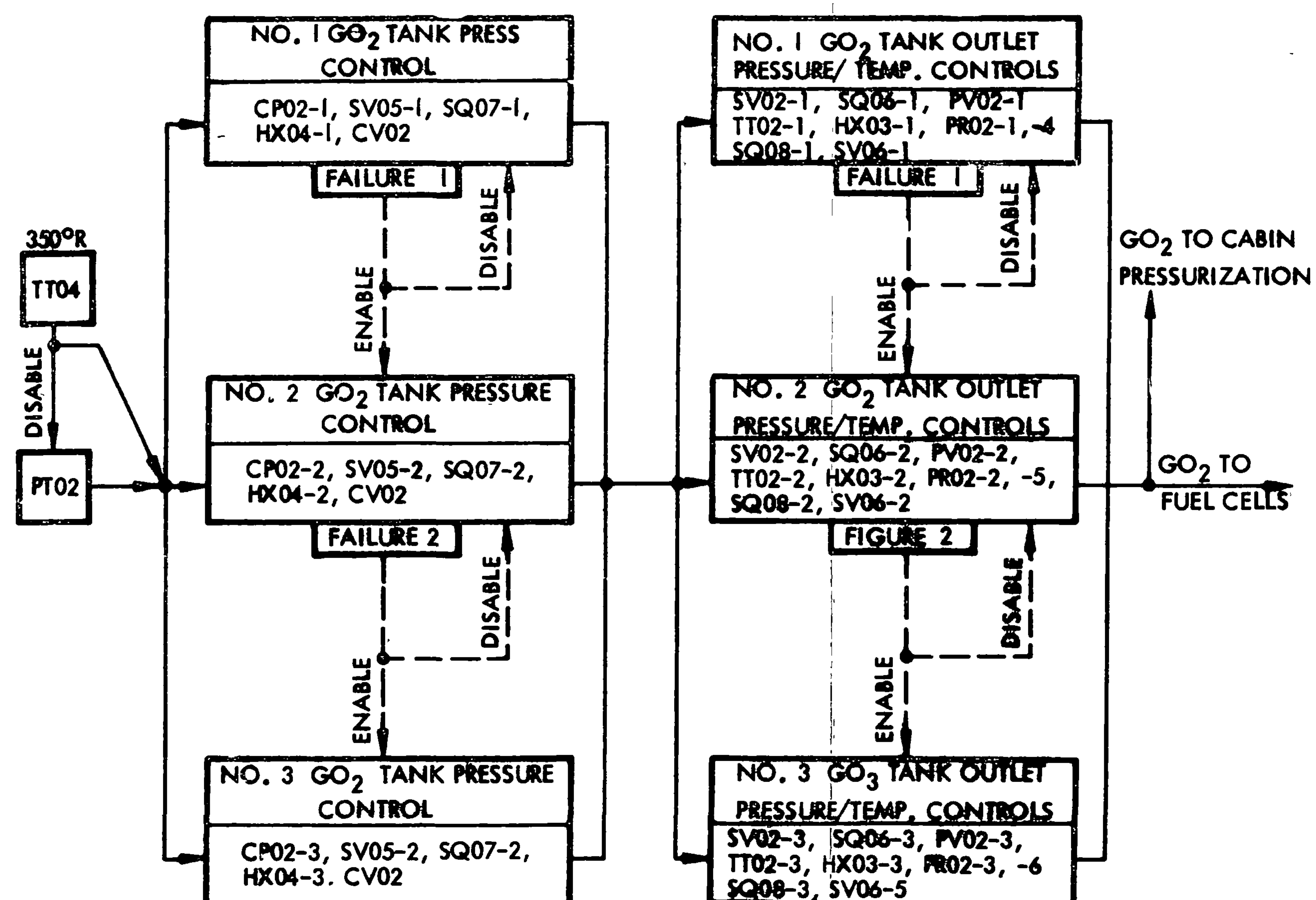

Fig. D-25 O_2 Fluid Conditioning Controls

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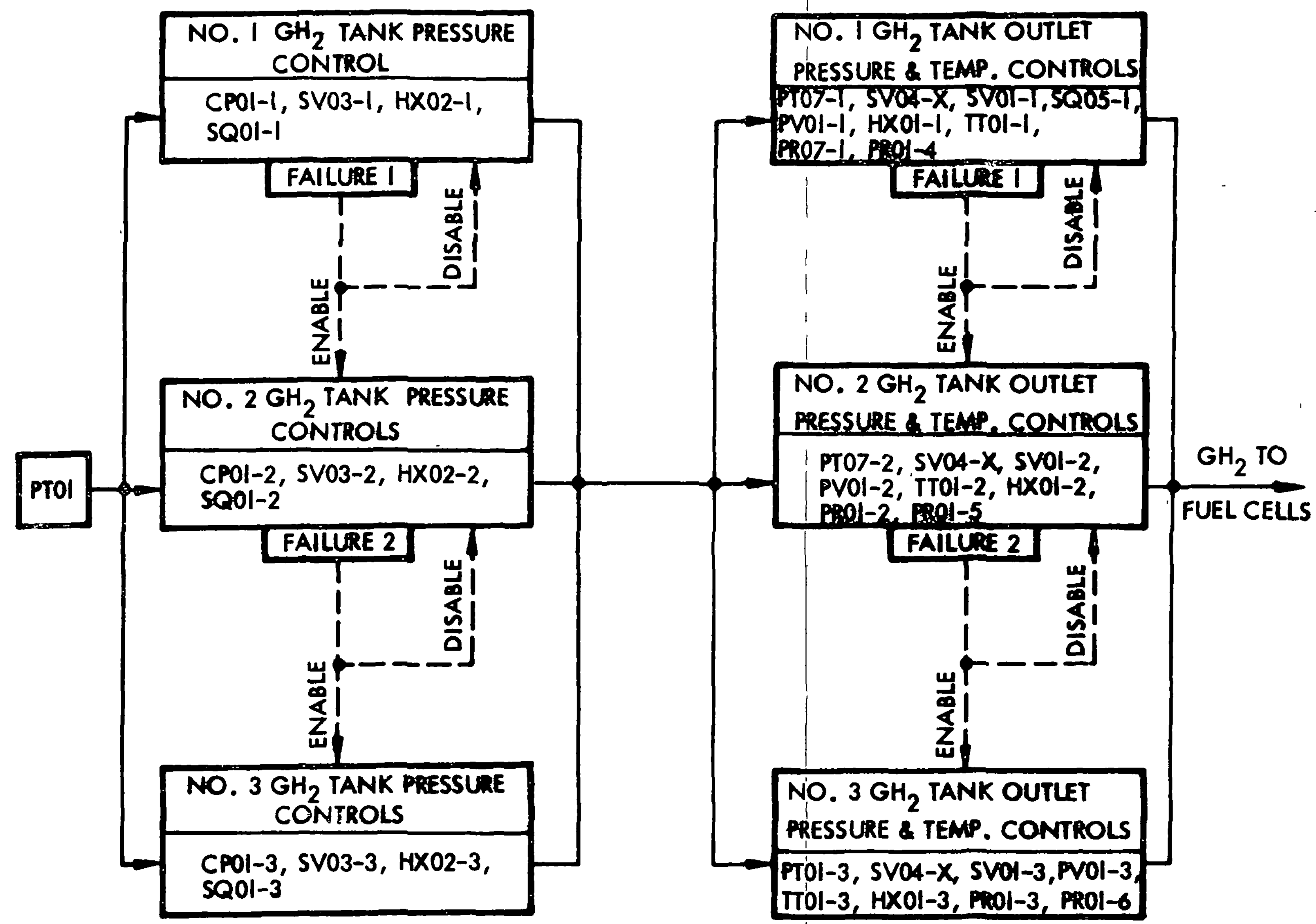

Fig. D-26 H_2 Fluid Conditioning Controls

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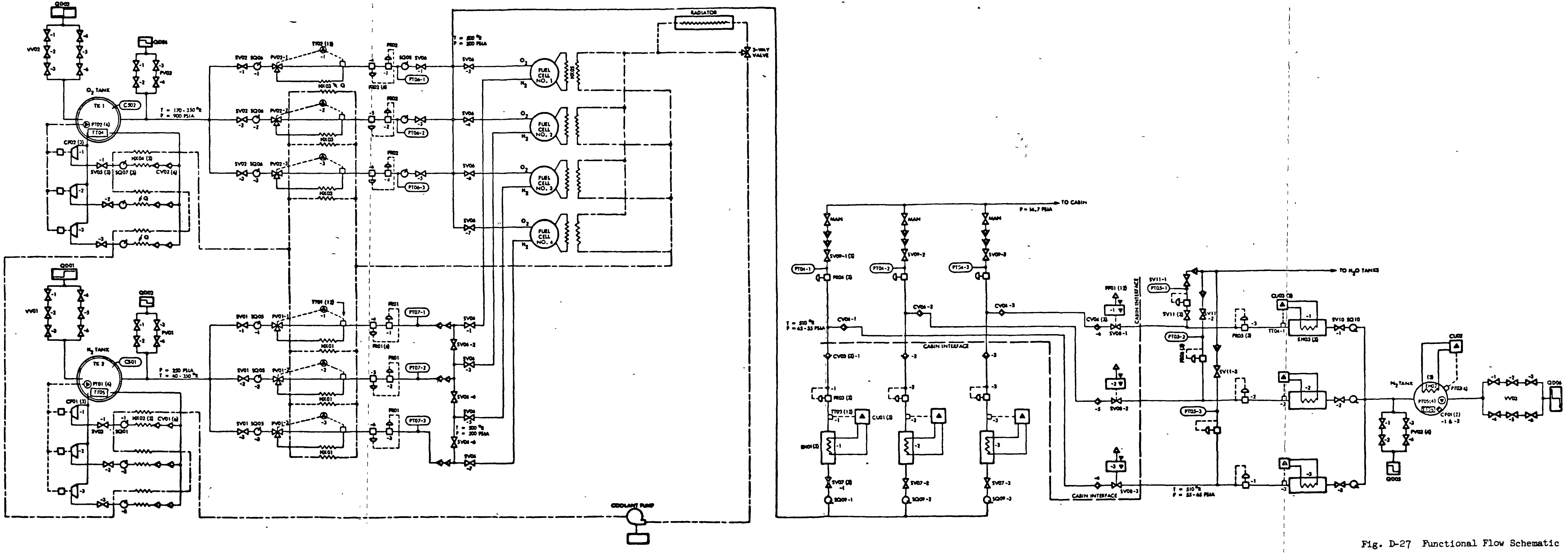

Fig. D-27 Functional Flow Schematic

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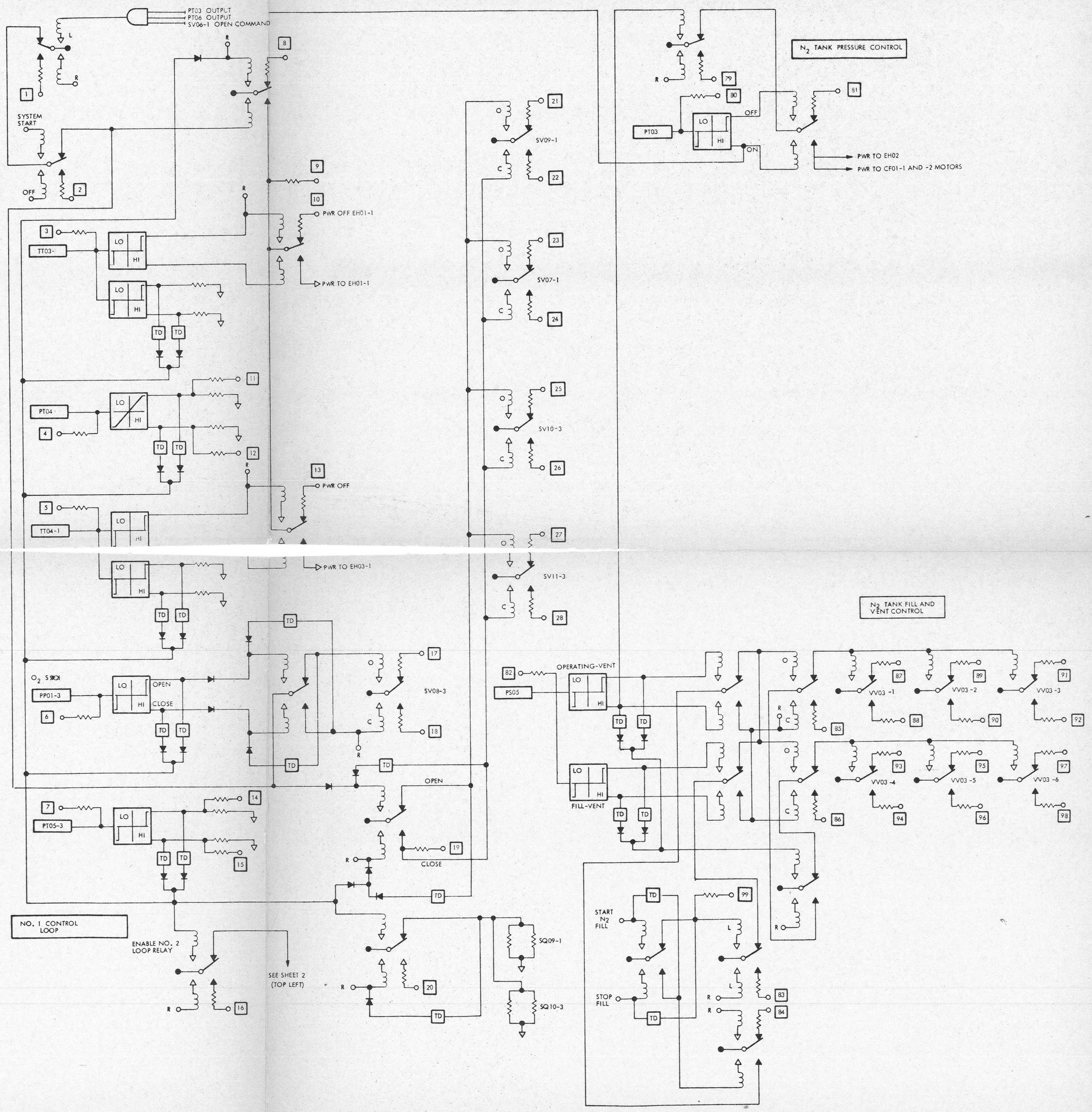

Fig. D-28A O_2 and N_2 Controls Schematic - Cabin Pressurization and H_2O Tank Pressurization (Sheet 1 of 2)

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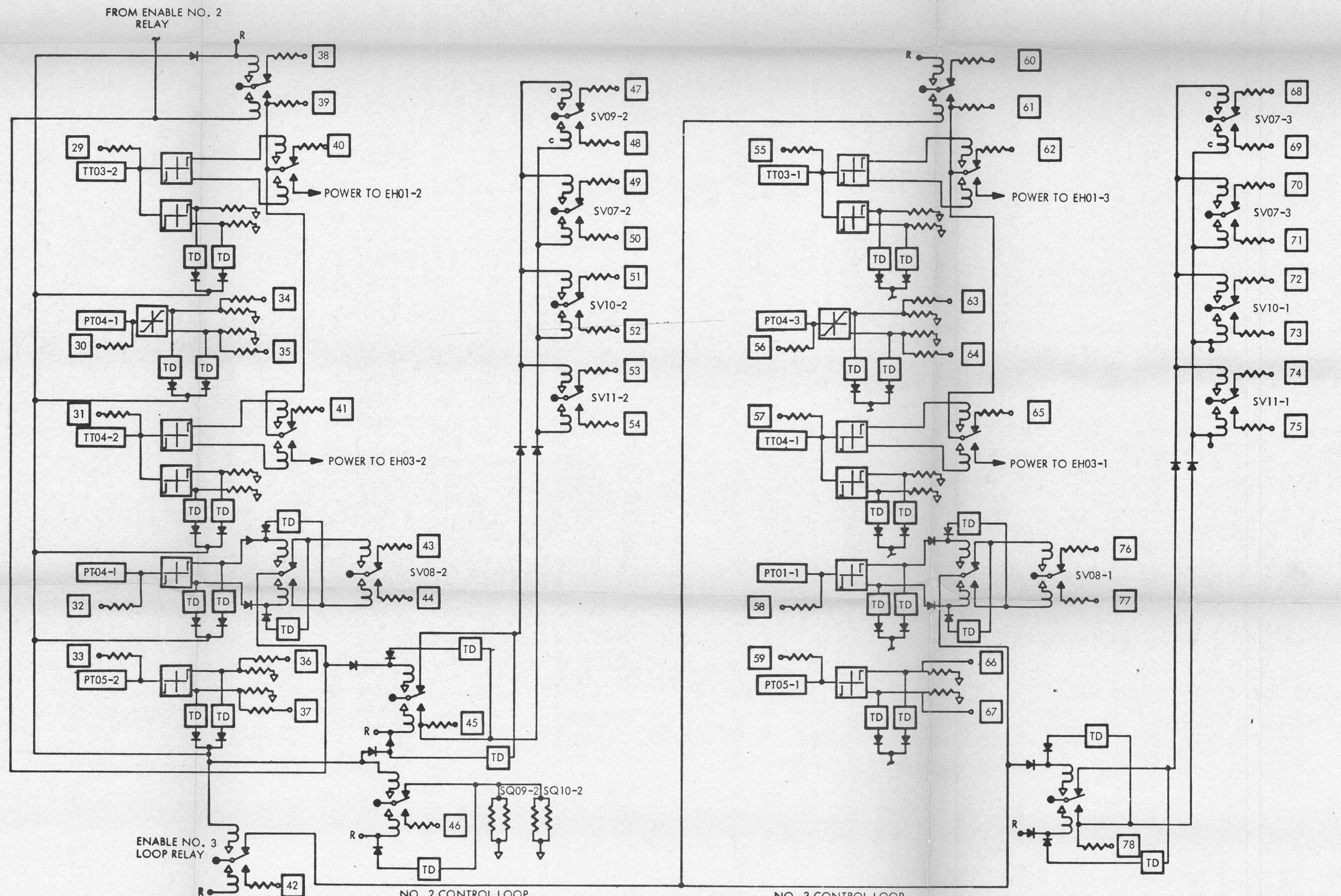

Fig. D-28B O_2 and N_2 Controls Schematic - Cabin Pressurization and H_2O Tank Pressurization (Sheet 2 of 2)

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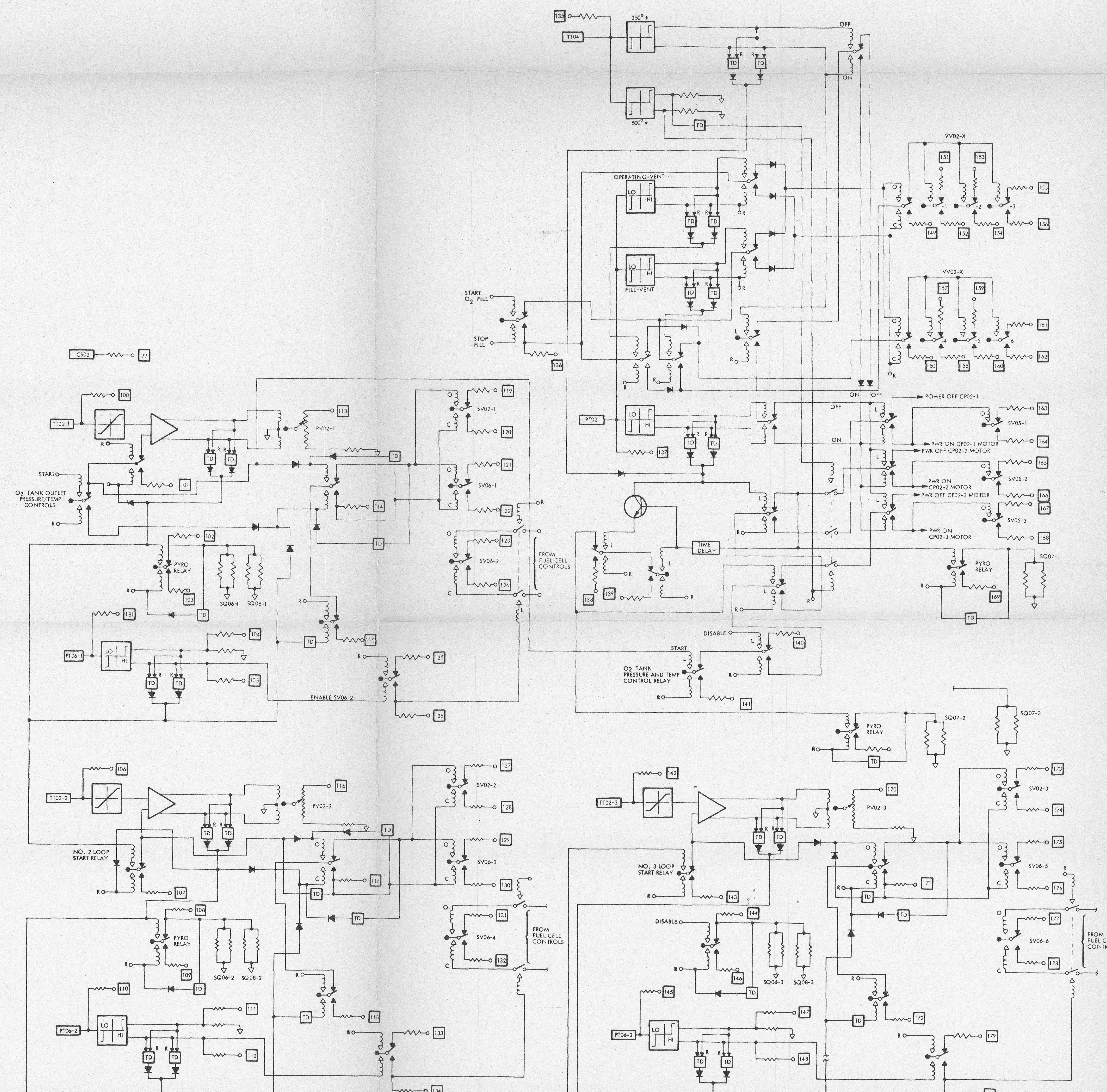

Fig. D-29 O_2 Fluid Conditioning Controls Schematic

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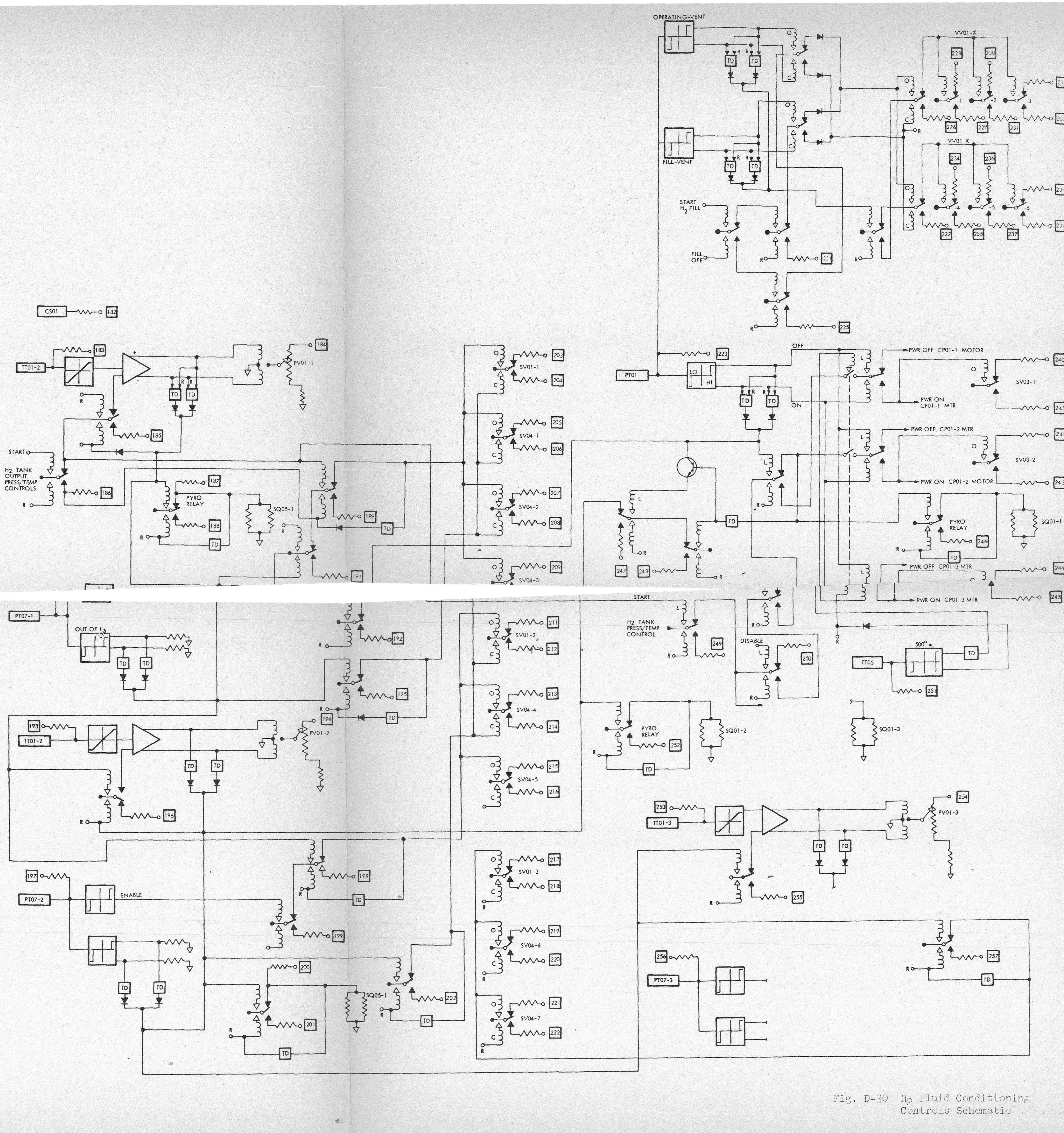

Fig. D-30 H_2 Fluid Conditioning Controls Schematic

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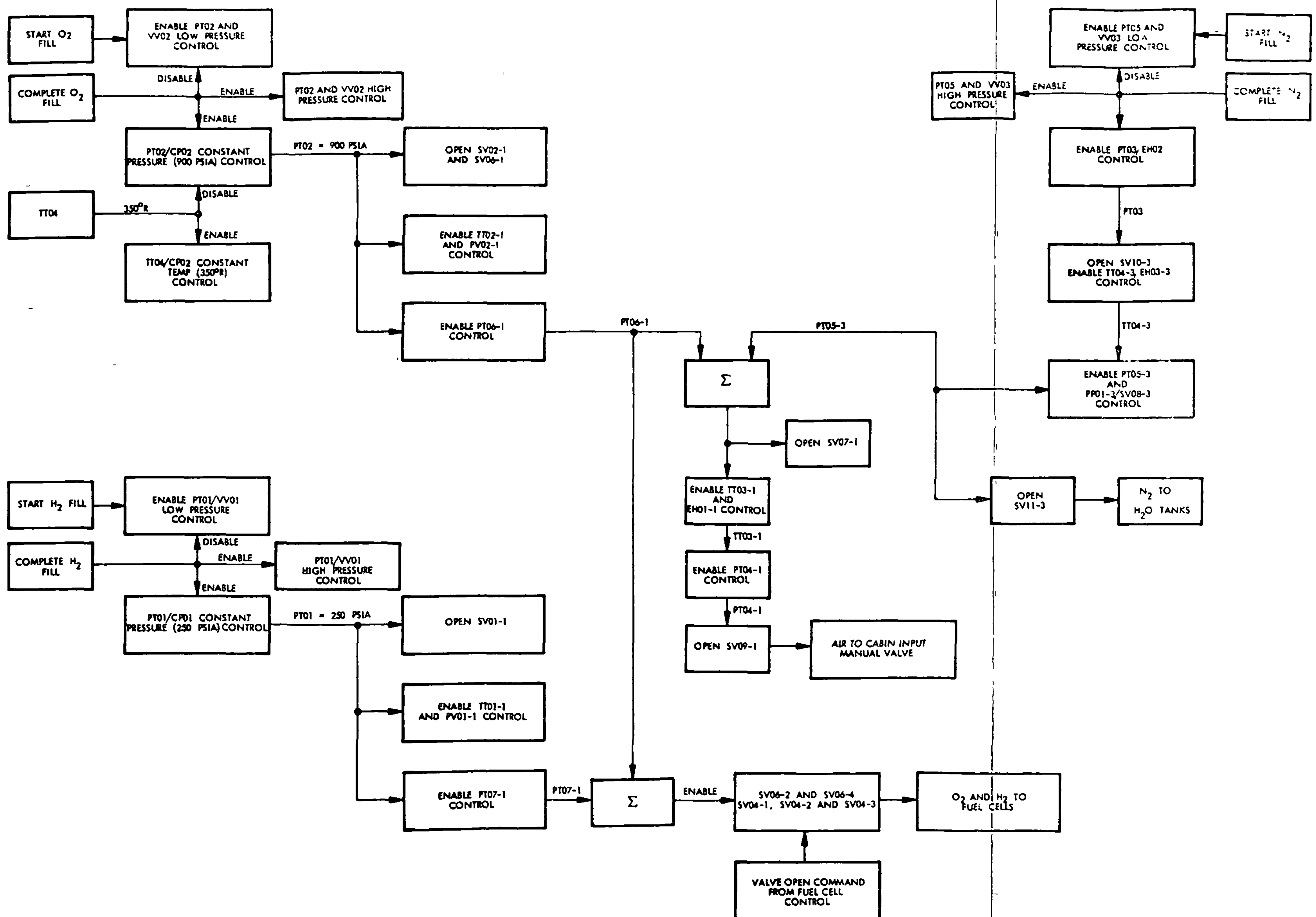

Fig. D-31 Event Flow Chart

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INSTRUMENTATION AND CONTROLS FOR SUPERCRITICAL FUEL CELL/LIFE SUPPORT SUPPLY SYSTEM

A. O_2 AND N_2 CONTROLS FOR CABIN PRESSURIZATION AND H_2O TANK PRESSURIZATION*

Monitor No.	Description
1	System Start Enable Relay Monitor 0 Vdc - System start ENABLED 5 Vdc - System start DISABLED
2	System Start Monitor 0 Vdc - System start 5 Vdc - OFF
3	TT03-1 Temp Xducer Analog Output Monitor 0 to 5 Vdc
4	PT04-1 Pressure Xducer Analog Output Monitor 0 to 5 Vdc
5	TT04-1 Temp Xducer Analog Output Monitor 0 to 5 Vdc
6	PP01-3 O_2 Partial Pressure Sensor Analog Output 0 to 5 Vdc
7	PT05 Pressure Xducer Analog Output 0 to 5 Vdc
8	Relay Monitor 5 Vdc - TT03-1 and TT04-1 outputs DISABLED 0 Vdc - TT03-1 and TT04-1 outputs ENABLED
9	Relay Monitor 5 Vdc - TT03-1 and TT04-1 outputs ENABLED 0 Vdc - TT03-1 and TT04-1 outputs DISABLED
10	Relay Monitor 0 Vdc - Power to EH01-1 5 Vdc - Power OFF
11	PT04-1 Output Limit Monitor 5 Vdc - Max output exceeded 0 Vdc - Less than max output

*(Fig. D-24)

Monitor No.	Description
12	PT04-1 Output Limit Monitor 5 Vdc - Less than min output 0 Vdc - Min output exceeded
13	Relay Monitor 0 Vdc - Power OFF 5 Vdc - Power to EH03-1
14	PT05-1 Pressure Xducer Output Limit Monitor 5 Vdc - Max output exceeded 0 Vdc - Less than max output
15	Pt05-3 Pressure Xducer Output Limit Monitor 5 Vdc - Less than min output 0 Vdc - More than min output
16	Relay Monitor 5 Vdc - No. 2 loop DISABLED 0 Vdc - No. 2 loop ENABLED
17	Valve Position Switch Monitor 5 Vdc - SV08-3 OPEN 0 Vdc - SV08-3 CLOSED
18	VPSM 5 Vdc - SV08-3 CLOSED 0 Vdc - SV08-3 OPEN
19	Valve Driver Monitor 5 Vdc - CLOSE SV09-1, SV07-1, SV10-3 and SV11-3 0 Vdc - OPEN SV09-1, SV07-1, SV10-3 and SV11-3
20	Squib Firing Relay Monitor 5 Vdc - Power OFF squibs 0 Vdc - Power to SQ09-1 and SQ10-3
21	VPSM 5 Vdc - SV09-1 OPEN 0 Vdc - SV09-1 CLOSED
22	VPSM 5 Vdc - SV09-1 CLOSED 0 Vdc - SV09-1 OPEN

Monitor No.	Description
23	VPSM 5 Vdc - SV07-1 OPEN 0 Vdc - SV07-1 CLOSED
24	VPSM 5 Vdc - SV07-1 CLOSED 0 Vdc - SV07-1 OPEN
25	VPSM 5 Vdc - SV10-3 OPEN 0 Vdc - SV10-3 CLOSED
26	VPSM 5 Vdc - SV10-3 CLOSED 0 Vdc - SV10-3 OPEN
27	VPSM 5 Vdc - SV11-3 OPEN 0 Vdc - SV11-3 CLOSED
28	VPSM 5 Vdc - SV11-3 CLOSED 0 Vdc - SV11-3 OPEN
29	TT03-2 Temp Xducer Analog Output 0 to 5 Vdc
30	PT04-1 Pressure Xducer Analog Output 0 to 5 Vdc
31	TT04-2 Temp Xducer Analog Output 0 to 5 Vdc
32	PP01-2 O_2 Partial Pressure Sensor Output 0 to 5 Vdc
33	PT05-2 Pressure Xducer Analog Output 0 to 5 Vdc
34	PT04-1 Output Limit Monitor 5 Vdc - Max output pressure exceeded 0 Vdc - Less than max output pressure

Monitor No.	Description
35	PT0401 Output Limit Monitor 5 Vdc - < minimum output pressure 0 Vdc - > minimum output pressure
36	PT05-2 Output Limit Monitor 5 Vdc - > max output pressure 0 Vdc - < max output pressure
37	PT05-2 Output Limit Monitor 5 Vdc - < minimum output pressure 0 Vdc - > minimum output pressure
38	Relay Monitor 5 Vdc - No. 2 loop DISABLED 0 Vdc - No. 2 loop ENABLED
39	Relay Monitor 5 Vdc - No. 2 loop ENABLED 0 Vdc - No. 2 loop DISABLED
40	Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to EH01-2
41	Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to EH03-2
42	Relay Monitor 5 Vdc - No. 3 loop DISABLED 0 Vdc - No. 3 loop ENABLED
43	VPSM 5 Vdc - SV08-2 OPEN 0 Vdc - SV08-2 CLOSED
44	VPSM 5 Vdc - SV08-2 CLOSED 0 Vdc - SV08-2 OPEN
45	Relay Monitor 5 Vdc - CLOSE SV08-2, SV07-2, SVio-2 and SV11-2 0 Vdc - OPEN SV09-2, SV07-2, SV10-2 and SV11-2

Monitor No.	Description
46	Pyro Relay Monitor 5 Vdc - Power OFF 0 Vdc - Actuate SQ09-2 and SQ10-2
47	VPSM 5 Vdc - SV09-2 OPEN 0 Vdc - SV09-2 CLOSED
48	VPSM 5 Vdc - SV09-2 CLOSED 0 Vdc - SV09-2 OPEN
49	VPSM 5 Vdc - SV07-2 OPEN 0 Vdc - SV07-2 CLOSED
50	VPSM 5 Vdc - SV07-2 CLOSED 0 Vdc - SV07-2 OPEN
51	VPSM 5 Vdc - SV10-2 OPEN 0 Vdc - SV10-2 CLOSED
52	VPSM 5 Vdc - SV10-2 CLOSED 0 Vdc - SV10-2 OPEN
53	VPSM 5 Vdc - SV11-2 OPEN 0 Vdc - SV11-2 CLOSED
54	VPSM 5 Vdc - SV11-2 CLOSED 0 Vdc - SV11-2 OPEN
55	TT03-3 Temp Xducer Analog Output 0 to 5 Vdc
56	PT04-3 Pressure Xducer Analog Output 0 to 5 Vdc
57	TT04-1 Temp Xducer Analog Output 0 to 5 Vdc

Monitor No.	Description
58	PP01 O_2 Partial Pressure Sensor Analog Output 0 to 5 Vdc
59	PT05-1 Pressure Xducer Analog Output 0 to 5 Vdc
60	Relay Monitor 5 Vdc - Output of TT03-3 and PT04-3 DISABLED 0 Vdc - Output of TT03-3 and PT04-3 ENABLED
61	Relay Monitor 5 Vdc - Output of TT03-3 and PT04-3 ENABLED 0 Vdc - Output of TT03-3 and PT04-3 DISABLED
62	Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to EH01-3
63	PT04-3 Output Limit Monitor 5 Vdc - $>$ max output 0 Vdc - $<$ max output
64	PT04-3 Output Limit Monitor 5 Vdc - $<$ minimum output 0 Vdc - $>$ minimum output
65	Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to EH03-1
66	PT05-1 Output Upper Limit Monitor 5 Vdc - $>$ max output 0 Vdc - $<$ max output
67	PT05-1 Output Lower Limit Monitor 5 Vdc - $<$ minimum output 0 Vdc - $>$ minimum output
68	VPSM 5 Vdc - SV09-3 OPEN 0 Vdc - SV09-3 CLOSE
69	VPSM 5 Vdc - SV09-3 CLOSE 0 Vdc - SV09-3 OPEN

Monitor No.	Description
70	VPSM 5 Vdc - SV07-3 OPEN 0 Vdc - SV07-3 CLOSE
71	VPSM 5 Vdc - SV07-3 CLOSE 0 Vdc - SV07-3 OPEN
72	VPSM 5 Vdc - SV10-1 OPEN 0 Vdc - SV10-1 CLOSE
73	VPSM 5 Vdc - SV10-1 CLOSE 0 Vdc - SV10-1 OPEN
74	VPSM 5 Vdc - SV11-1 OPEN 0 Vdc - SV11-1 CLOSE
75	VPSM 5 Vdc - SV11-1 CLOSE 0 Vdc - SV11-1 OPEN
76	VPSM 5 Vdc - SV08-1 OPEN 0 Vdc - SV08-1 CLOSE
77	VPSM 5 Vdc - SV08-1 CLOSE 0 Vdc - SV08-1 OPEN
78	Relay Monitor 5 Vdc - CLOSE SV09-3, SV07-3, SV10-1 and SV11-1 0 Vdc - OPEN SV09-3, SV07-3, SV10-1 and SV11-1
79	Relay Monitor 5 Vdc - PT03 output DISABLED 0 Vdc - PT03 output ENABLED
80	PT03 Pressure Xducer Analog Output 0 to 5 Vdc
81	Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to EH02 and CF01-1, -2

Monitor No.	Description
82	PS05 Pressure Xducer Analog Output 0 to 5 Vdc
83	Relay Monitor 5 Vdc - N_2 fill/vent control DISABLED 0 Vdc - N_2 fill/vent control ENABLED
84	Relay Monitor 5 Vdc - N_2 operating/vent control DISABLED 0 Vdc - N_2 operating/vent control ENABLED
85	Relay Monitor 5 Vdc - VV03-1, -2, -3 vent valves CLOSED 0 Vdc - VV03-1, -2, -3 vent valves OPEN
86	Relay Monitor 5 Vdc - VV03-4, -5, -6 vent valves CLOSED 0 Vdc - VV03-4, -5, -6 vent valves OPEN
87	VPSM 5 Vdc - VV03-1 OPEN 0 Vdc - VV03-1 CLOSED
88	VPSM 5 Vdc - VV03-1 CLOSED 0 Vdc - VV03-1 OPEN
89	VPSM 5 Vdc - VV03-2 OPEN 0 Vdc - VV03-2 CLOSED
90	VPSM 5 Vdc - VV03-2 CLOSED 0 Vdc - VV03-2 OPEN
91	VPSM 5 Vdc - VV03-3 OPEN 0 Vdc - VV03-3 CLOSED
92	VPSM 5 Vdc - VV03-3 CLOSED 0 Vdc - VV03-3 OPEN

Monitor No.	Description
93	VPSM 5 Vdc - VV03-4 OPEN 0 Vdc - VV03-4 CLOSED
94	VPSM 5 Vdc - VV03-4 CLOSED 0 Vdc - VV03-4 OPEN
95	VPSM 5 Vdc - VV03-5 OPEN 0 Vdc - VV03-5 CLOSED
96	VPSM 5 Vdc - VV03-5 CLOSED 0 Vdc - VV03-5 OPEN
97	VPSM 5 Vdc - VV03-6 OPEN 0 Vdc - VV03-6 CLOSED
98	VPSM 5 Vdc - VV03-6 CLOSED 0 Ved - VV03-6 OPEN

B. O_2 FLUID CONDITIONING FOR SUPERCRITICAL FUEL CELL AND LIFE SUPPORT SUPPLY*

Monitor No.	Description
99	CS02 - Capacitance Sensor Analog Output 0 to 5 Vdc
100	TT02-1 Temp Xducer Analog Output 0 to 5 Vdc
101	Relay Monitor 5 Vdc - TT02-1 output DISABLED 0 Vdc - TT02-1 output ENABLED
102	Pyro Relay Monitor 5 Vdc - Power ON SQ06-1 and SQ08-1 0 Vdc - Power OFF
103	Pyro Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power ON SQ06-1 and SQ08-1
104	PT06-1 Pressure Xducer High Limit Monitor 5 Vdc - > max limit 0 Vdc - < max limit
105	PT06-1 Pressure Xducer Low Limit Monitor 5 Vdc - < low limit 0 Ved - > low limit
106	TT02-2 Temp Xducer Analog Output 0 to 5 Vdc
107	Relay Monitor 5 Vdc - TT02-2 output DISABLED 0 Vdc - TT02-2 output ENABLED
108	Pyro Relay Monitor 5 Vdc - Power to SQ06-2 and SQ08-2 0 Ved - Power OFF
109	Pyro Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to SQ06-2 and SQ08-2

*Fig. D-25

Monitor No.	Description
110	PT06-2 Pressure Xducer Analog Output 0 to 5 Vdc
111	PT06-2 Pressure Xducer High Limit Monitor 5 Vdc - max limit 0 Vdc - max limit
112	PT06-2 Pressure Xducer Low Limit Monitor 5 Vdc - low limit 0 Vdc - low limit
113	PV02-1 Position Xducer Analog Output 0 to 5 Vdc
114	Relay Monitor 5 Vdc - CLOSE SV02-1, SV06-1, -2 0 Vdc - OPEN SV02-1, SV06-1, -2
115	Relay Monitor 5 Vdc - SV02-1, SV06-1, -2 DISABLED 0 Vcd - SV02-1, SV06-1, -2 ENABLED
116	PV02-2 Position Xducer Analog Output 0 to 5 Vdc
117	Relay Monitor 5 Vdc - SV02-2 and SV06-3 CLOSED 0 Vdc - SV02-2 and SV06-3 OPEN
118	Relay Monitor 5 Vdc - SV02-2 and SV06-3 DISABLED 0 Vcd - SV02-2 and SV06-3 ENABLED
119	VPSM 5 Vdc - SV02-1 OPEN 0 Vdc - SV02-1 CLOSED
120	VPSM 5 Vdc - SV02-1 CLOSED 0 Vdc - SV02-1 OPEN
121	VPSM 5 Vdc - SV06-1 OPEN 0 Vdc - SV06-1 CLOSED

Monitor No.	Description
122	VPSM 5 Vdc - SV06-1 CLOSED 0 Vdc - SV06-1 OPEN
123	VPSM 5 Vdc - SV06-2 OPEN 0 Vdc - SV06-2 CLOSED
124	VPSM 5 Vdc - SV06-2 CLOSED 0 Vdc - SV06-2 OPEN
125	VPSM 5 Vdc - SV02-2 OPEN 0 Vdc - SV02-2 CLOSED
126	VPSM 5 Vdc - SV02-2 CLOSED 0 Vdc - SV02-2 OPEN
127	VPSM 5 Vdc - SV06-3 OPEN 0 Vdc - SV06-3 CLOSED
128	VPSM 5 Vdc - SV06-3 CLOSED 0 Vdc - SV06-3 OPEN
129	VPSM 5 Vdc - SV06-3 OPEN 0 Vdc - SV06-3 CLOSED
130	VPSM 5 Vdc - SV06-3 CLOSED 0 Vdc - SV06-3 OPEN
131	VPSM 5 Vdc - SV06-4 OPEN 0 Vdc - SV06-4 CLOSED
132	VPSM 5 Vdc - SV06-4 CLOSED 0 Vdc - SV06-4 OPEN
133	Relay Monitor 5 Vdc - SV06-4 DISABLED 0 Vdc - SV06-4 ENABLED

Monitor No.	Description
134	Relay Monitor 5 Vdc - SV06-4 ENABLED 0 Vdc - SV06-4 DISABLED
135	TT04 Temp Xducer Analog Output 0 to 5 Vdc
136	O_2 Tank Fill Monitor 5 Vdc - Stop fill 0 Vdc - Start fill
137	PT02 Pressure Xducer Analog Output 0 to 5 Vdc
138	Relay Monitor 5 Vdc - SQ07-2 pyro relay DISABLED (Reset) 0 Vdc - SQ07-2 pyro relay ENABLED
139	Relay Monitor 5 Vdc - Reset 0 Vdc - Power to No. 138 relay monitor
140	Relay Monitor 5 Vdc - DISABLE 0 Vdc - Reset
141	Relay Monitor 5 Vdc - Reset 0 Vdc - Start command for O_2 tank press/temp control
142	TT02-3 Temp Xducer Analog Output 0 to 5 Vdc
143	Start Relay Monitor 5 Vdc - No. 3 loop DISABLED 0 Vdc - Start No. 3 loop
144	Squib Monitor 5 Vdc - Fire SQ06-3 and SQ08-3 0 Vdc - Power OFF Sq06-3 and S^08-3
145	PT06-3 Pressure Xducer Analog Output 0 to 5 Vdc

Monitor No.	Description
146	Squib Relay Monitor 5 Vdc - Power OFF SQ06-3 and SQ08-3 0 Vdc - Power ON
147	PT06-3 Pressure Xducer High Limit Output Monitor 5 Vdc - $>$ max output 0 Vdc - $<$ max output
148	PT06-3 Pressure Xducer Low Limit Output Monitor 5 Vdc - $<$ low limit 0 Vdc - $>$ low limit
149	Valve Driver Monitor 5 Vdc - Power OFF valves (CLOSED) 0 Vdc - Power ON (OPEN) VV02-1, -2 and -3
150	Valve Driver Monitor 5 Vdc - Power OFF valves (CLOSED) 0 Vdc - Power ON (OPEN) VV02-3, -4 and -5
151	VPSM 5 Vdc - VV02-1 OPEN 0 Vdc - VV02-1 CLOSED
152	VPSM 5 Vdc - VV02-1 CLOSED 0 Vdc - VV02-1 OPEN
153	VPSM 5 Vdc - VV02-2 OPEN 0 Vdc - VV02-2 CLOSED
154	VPSM 5 Vdc - VV02-2 CLOSED 0 Vdc - VV02-2 OPEN
155	VPSM 5 Vdc - VV02-3 OPEN 0 Vdc - VV02-3 CLOSED
156	VPSM 5 Vdc - VV02-3 CLOSED 0 Vdc - VV02-3 OPEN

Monitor No.	Description
157	VPSM 5 Vdc - VV02-4 OPEN 0 Vdc - VV02-4 CLOSED
158	VPSM 5 Vdc - VV02-4 CLOSED 0 Vdc - VV02-4 OPEN
159	VPSM 5 Vdc - VV02-5 OPEN 0 Vdc - VV02-5 CLOSED
160	VPSM 5 Vdc - VV02-5 CLOSED 0 Vdc - VV02-5 OPEN
161	VPSM 5 Vdc - VV02-6 OPEN 0 Vdc - VV02-6 CLOSED
162	VPSM 5 Vdc - VV02-6 CLOSED 0 Vdc - VV02-6 OPEN
163	VPSM 5 Vdc - SV05-1 OPEN 0 Vdc - SV05-1 CLOSED
164	VPSM 5 Vdc - SV05-1 CLOSED 0 Vdc - SV05-1 OPEN
165	VPSM 5 Vdc - SV05-2 OPEN 0 Vdc - SV05-2 CLOSED
166	VPSM 5 Vdc - SV05-2 CLOSED 0 Vdc - SV05-2 OPEN
167	VPSM 5 Vdc - SV05-3 OPEN 0 Vdc - SV05-3 CLOSED

Monitor No.	Description
168	VPSM 5 Vdc - SV05-3 CLOSED 0 Vdc - SV05-3 OPEN
169	Pyro Relay Monitor 5 Vdc - Power OFF SQ07-1 0 Vdc - Power ON SQ07-1
170	PV02-3 Position Xducer Analog Output 0 to 5 Vdc
171	Relay Monitor 5 Vdc - Power to closing coil of SV02-3 and SV06-5 0 Vdc - Power to open coil of SV02-3 and SV06-5
172	Relay Monitor 5 Vdc - Reset 0 Vdc - ENABLE valve driver relay for SV02-3 and SV06-5
173	VPSM 5 Vdc - SV02-3 OPEN 0 Vdc - SV02-3 CLOSED
174	VPSM 5 Vdc - SV02-3 CLOSED 0 Vdc - SV02-3 OPEN
175	VPSM 5 Vdc - SV06-5 OPEN 0 Vdc - SV06-5 CLOSED
176	VPSM 5 Vdc - SV06-5 CLOSED 0 Vdc - SV06-5 OPEN
177	VPSM 5 Vdc - SV06-6 OPEN 0 Vdc - SV06-6 CLOSED
178	VPSM 5 Vdc - SV06-6 CLOSED 0 Vdc - SV06-6 OPEN

Monitor No.	Description
179	Relay Monitor 5 Vdc - Reset 0 Vdc - ENABLE SV06-6 valve driver
180	Relay Monitor 5 Vdc - ENABLE SV06-6 valve driver 0 Vdc - Reset
181	PT06-1 Pressure Xducer Analog Output 0 to 5 Vdc

C. H_2 FLUID CONDITIONING FOR SUPERCRITICAL FUEL CELL AND LIFE SUPPORT SUPPLY*

Monitor No.	Description
182	CS01 Capacitance Sensor Analog Output 0 to 5 Vdc
183	TT01-2 Temp Xducer Analog Output 0 to 5 Vdc
184	PV01 Position Xducer Analog Output 0 to 5 Vdc
185	Relay Monitor 5 Vdc - TT01-2 output DISABLED 0 Vdc - TT01-2 output ENABLED
186	Start Relay Monitor 5 Vdc - OFF 0 Vdc - Start H_2 tank outlet pressure and temp controls
187	Pyro Relay Monitor 5 Vdc - Power to SQ05-1 0 Vdc - Power OFF
188	Pyro Relay Monitor 5 Vdc - Power OFF (Reset) 0 Vdc - Power to SQ05-1
189	Valve(s) Driver Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to open coil of SV01-1, SV04-1, SV04-2 and SV04-3
190	PT07-1 Pressure Xducer Analog Output 0 to 5 Vdc
191	Relay Monitor 5 Vdc - DISABLE No. 189 relay 0 Vdc - ENABLE No. 189 relay
192	Relay Monitor 5 Vdc - DISABLE No. 192 relay 0 Vdc - ENABLE

*Fig. D-118

Monitor No.	Description
193	TT01-2 Temp Xducer Analog Output 0 to 5 Vdc
194	PV01 Position Xducer Analog Output 0 to 5 Vdc
195	Valve(s) Driver Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to close coil of SV01-1, SV04-1, SV04-2 and SV04-3
196	Relay Monitor 5 Vdc - TT01-2 output DISABLED 0 Vdc - TT01-2 output ENABLED
197	PT07-2 Pressure Xducer Analog Output 0 to 5 Vdc
198	Valve(s) Driver Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to open coil(s) of SV01-2, SV04-4 and SV04-5
199	Relay Monitor 5 Vdc - Power OFF 0 Vdc - ENABLE (power ON) No. 198 relay
200	Pyro Relay Monitor 5 Vdc - Power to SQ05-1 0 Vdc - Power OFF
201	Pyro Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to SQ05-1
202	Valve(s) Driver Relay Monitor 5 Vdc - Power OFF 0 Vdc - Power to closing coil(s) of SV04-3, SV01-2, and SV04-4
203	VPSM 5 Vdc - SV01-1 OPEN 0 Vdc - SV01-1 CLOSED
204	VPSM 5 Vdc - SV01-1 CLOSED 0 Vdc - SV01-1 OPEN

Monitor No.	Description
205	VPSM 5 Vdc - SV04-1 OPEN 0 Vdc - SV04-1 CLOSED
206	VPSM 5 Vdc - SV04-1 CLOSED 0 Vdc - SV04-1 OPEN
207	VPSM 5 Vdc - SV04-2 OPEN 0 Vdc - SV04-2 CLOSED
208	VPSM 5 Vdc - SV04-2 CLOSED 0 Vdc - SV04-2 OPEN
209	VPSM 5 Vdc - SV04-3 OPENED 0 Vdc - SV04-3 CLOSED
210	VPSM 5 Vdc - SV04-3 CLOSED 0 Vdc - SV04-3 OPENED
211	VPSM 5 Vdc - SV01-2 OPENED 0 Vdc - SV01-2 CLOSED
212	VPSM 5 Vdc - SV01-2 CLOSED 0 Vdc - SV01-2 OPENED
213	VPSM 5 Vdc - SV04-4 OPENED 0 Vdc - SV04-4 CLOSED
214	VPSM 5 Vdc - SV04-4 CLOSED 0 Vdc - SV04-4 OPENED
215	VPSM 5 Vdc - SV04-5 OPENED 0 Vdc - SV04-5 CLOSED

Monitor No.	Description
216	VPSM 5 Vdc - SV04-5 CLOSED 0 Vdc - SV04-5 OPENED
217	VPSM 5 Vdc - SV01-3 OPENED 0 Vdc - SV01-3 CLOSED
218	VPSM 5 Vdc - SV01-3 CLOSED 0 Vdc - SV01-3 OPENED
219	VPSM 5 Vdc - SV04-6 OPENED 0 Vdc - SV04-6 CLOSED
220	VPSM 5 Vdc - SV04-6 CLOSED 0 Vdc - SV04-6 OPENED
221	VPSM 5 Vdc - SV04-7 OPENED 0 Vdc - SV04-7 CLOSED
222	VPSM 5 Vdc - SV04-7 CLOSED 0 Vdc - SV04-7 OPENED
223	PT01 Pressure Xducer Analog Output 0 to 5 Vdc
224	Relay Monitor 5 Vdc - Power OFF (Reset) 0 Vdc - Power to valve(s) driver relay for closing VV01-1 through 6
225	Relay Monitor 5 Vdc - Reset 0 Vdc - Power to valve(s) driver relay for opening VV01-1 through VV01-6
226	Valve Driver Relay 5 Vdc - Power OFF (Reset) 0 Vdc - Power to (OPEN) VV01-1, -2, and -3

Monitor No.	Description
227	Valve Driver Relay 5 Vdc - Power OFF (Reset) 0 Vdc - Power to (OPEN) VV01-4, -5 and -6
228	VPSM 5 Vdc - OPENED VV01-1 0 Vdc - CLOSED VV01-1
229	VPSM 5 Vdc - CLOSED VV01-1 0 Vdc - OPENED VV01-1
230	VPSM 5 Vdc - OPENED VV01-2 0 Vdc - CLOSED VV01-2
231	VPSM 5 Vdc - CLOSED VV01-2 0 Vdc - OPENED VV01-2
232	VPSM 5 Vdc - OPENED VV01-3 0 Vdc - CLOSED VV01-3
233	VPSM 5 Vdc - CLOSED VV01-3 0 Vdc - OPENED VV01-3
234	VPSM 5 Vdc - OPENED VV01-4 0 Vdc - CLOSED VV01-4
235	VPSM 5 Vdc - CLOSED VV01-4 0 Vdc - OPENED VV01-4
236	VPSM 5 Vdc - OPENED VV01-5 0 Vdc - CLOSED VV01-5
237	VPSM 5 Vdc - CLOSED VV01-5 0 Vdc - OPENED VV01-5
238	VPSM 5 Vdc - OPENED VV01-6 0 Vdc - CLOSED VV01-6

Monitor No. | **Description**

239 VPSM

5 Vdc - CLOSED VV01-6
0 Vdc - OPENED VV01-6

240 VPSM

5 Vdc - OPENED SV03-1
0 Vdc - CLOSED SV03-1

241 VPSM

5 Vdc - CLOSED SV03-1
0 Vdc - OPENED SV03-1

242 VPSM

5 Vdc - OPENED SV03-2
0 Vdc - CLOSED SV03-2

243 VPSM

5 Vdc - CLOSED SV03-2
0 Vdc - OPENED SV03-2

244 VPSM

5 Vdc - OPENED SV03-3
0 Vdc - CLOSED SV03-3

245 VPSM

5 Vdc - CLOSED SV03-3
0 Vdc - OPENED SV03-3

246 Pyro Relay Monitor

5 Vdc - Power OFF (Reset)
0 Vdc - Power to SQ01-1

247 Relay Monitor

5 Vdc - Power OFF (Reset)
0 Vdc - ENABLE power relay for CP01-3 motor and SV03-3 valve

248 Relay Monitor

5 Vdc - Reset
0 Vdc - ENABLE No. 247 relay

249 Relay Monitor

5 Vdc - Reset
0 Vdc - Start H_2 tank pressure/temp controls

Monitor No.	Description
250	Relay Monitor 5 Vdc - No. 3 loop DISABLED 0 Vdc - Reset
251	TT05 Temp Xducer Analog Output 0 to 5 Vdc
252	Pyro Relay Monitor 5 Vdc - Power OFF (Reset) 0 Vdc - Power to SQ01-2
253	TT01-3 Temp Xducer Analog Output 0 to 5 Vdc
254	PV01-3 Position Xducer Analog Output 0 to 5 Vdc
255	Enable Relay Monitor 5 Vdc - TT01-3 output DISABLED 0 Vdc - TT01-3 output ENABLED
256	PT07-3 Pressure Xducer Analog Output 0 to 5 Vdc
257	Relay Monitor 5 Vdc - Reset 0 Vdc - Power to OPEN coils of SV01-3, SV04-6 and SV04-7

Appendix E

INITIAL COMPONENT REDUNDANCY EVALUATIONS

Initial component redundancy evaluations were performed for typical subsystems without redundancy. The purpose of these evaluations was to determine the components in the System which significantly affect reliability. The procedure which was employed was:

(1) The SETA II computer program was employed in the analyses. For each component, the effect on overall system reliability was examined for having "N" number of redundancies. Thereby, the "value" of each component was examined for different types of redundancy.

(2) This data was examined to determine which components significantly increased reliability by being redundant. The best type of redundancy was specified.

The results of the evaluations are presented in Figure E-1 through E-14. The location of the redundancies are shown on the schematics.

The final schematics resulted from consideration of these evaluations and the satisfaction of the Fail Operational/Fail Safe criteria.

. FUNCTIONAL REDUNDANCY APPRAISAL.

All Check Valves: 2 in series.
All Pressure Switches: 2 out of 3, voting.
SV03 & SV04: Parallel active redundant valves on each.

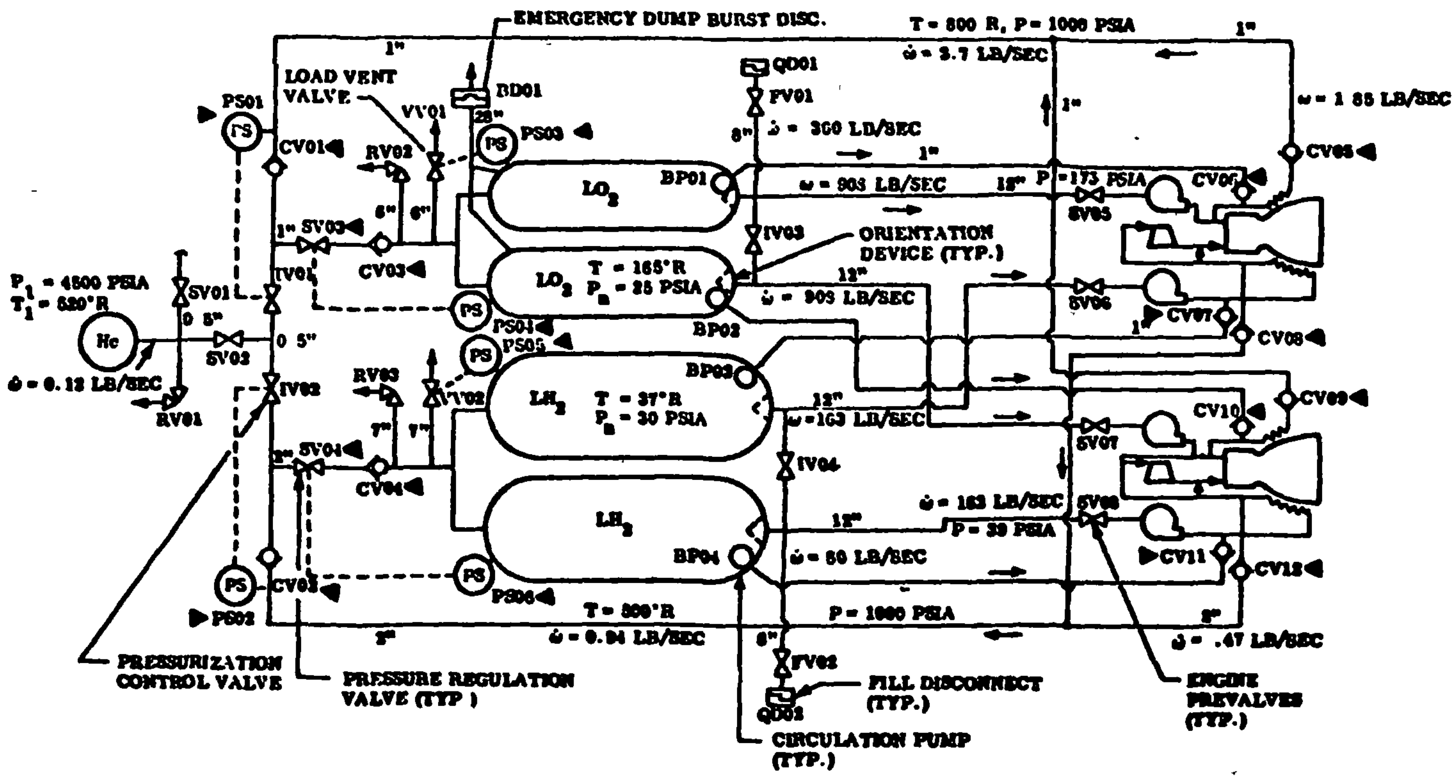

Fig. E-1 Orbit Injection Propulsion System

LMSC-A991396

FUNCTIONAL REDUNDANCY APPRAISAL

All Check Valves: 2 in series.
All Pressure Switches: 2 out of 3, voting.

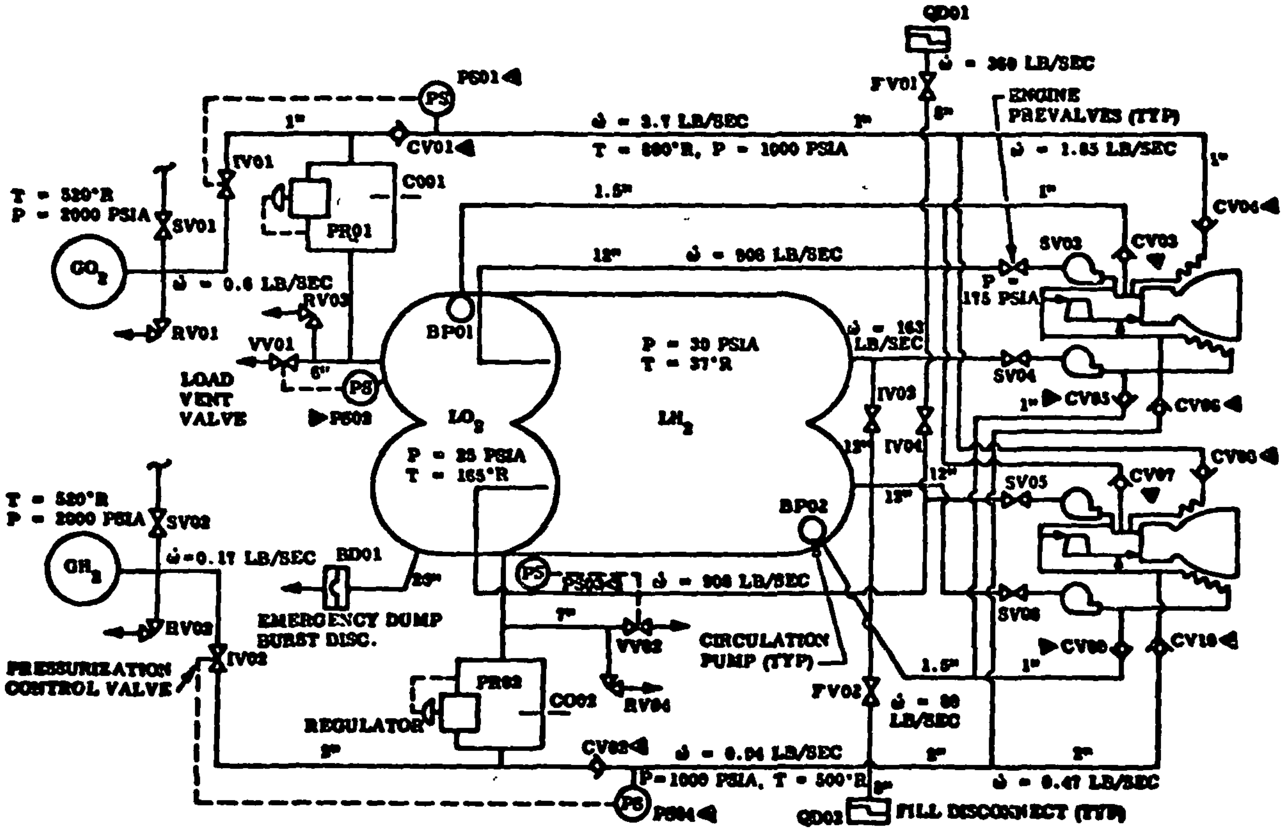

Fig E-2 Orbit Injection Propulsion System

FUNCTIONAL REDUNDANCY APPRAISAL

See following page.

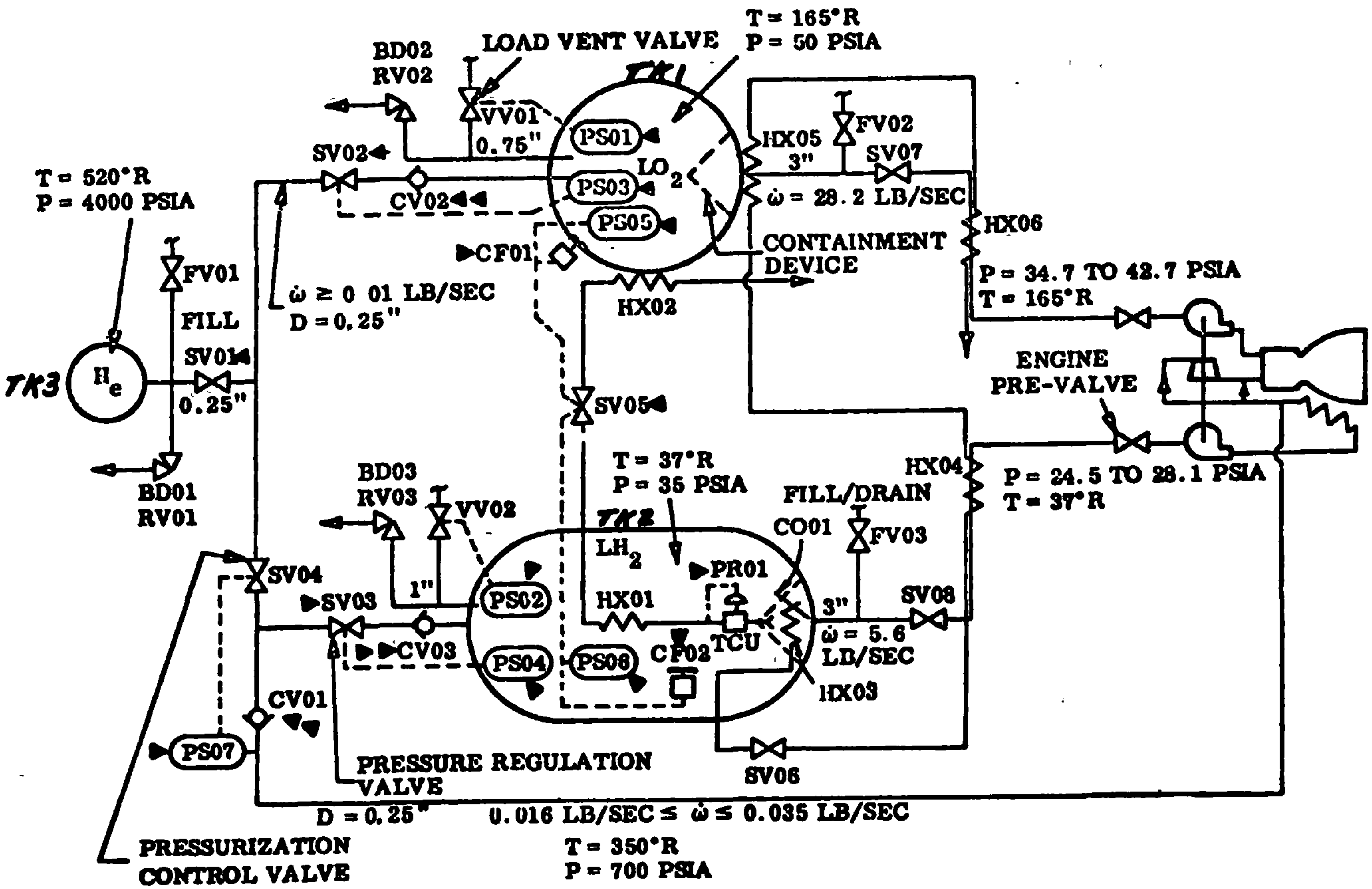

Fig. E-3 Orbit Maneuver Propulsion System

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ORBIT MANEUVER PROPULSION SYSTEM

FUNCTIONAL REDUNDANCY APPRAISAL

All Check Valves; 2 out of 4, active, quadredundant for high duty cycle.

All Pressure Switches: 2 out of 3, voting.

PR01: 2 in parallel, for failure to regulate failing closed.

CF01 & CFo2: 2 in parallel, active

SV05
SV02 : 2 in parallel, active for failure to open. (Each valve)
SV03

SV01: Squib-actuated valve in parallel with solonoid valve for failure to open.

Fig. E-3 (cont'd)

FUNCTIONAL REDUNDANCY APPRAISAL

See following page.

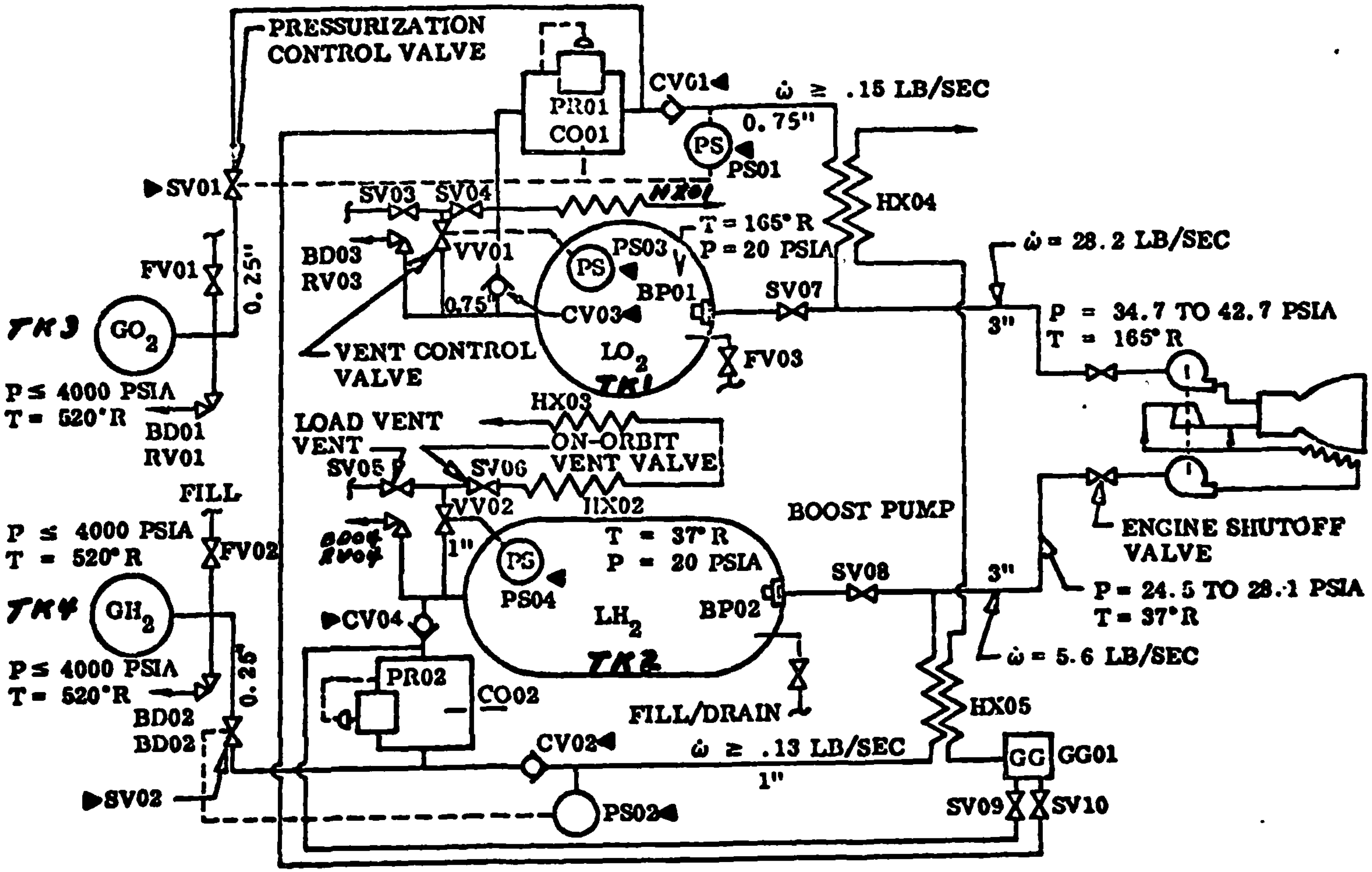

Fig. E-4 Orbit Maneuver Propulsion System

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ORBIT MANEUVER PROPULSION SYSTEM (OMPS-2)

FUNCTIONAL REDUNDANCY APPRAISAL

All Check Valves: 2 in series

All Pressure Switches: 2 out of 3, voting

SV01 }
SV02 } : 2 in parallel, active for failure to open (Each valve).

Fig. E-4 (cont'd)

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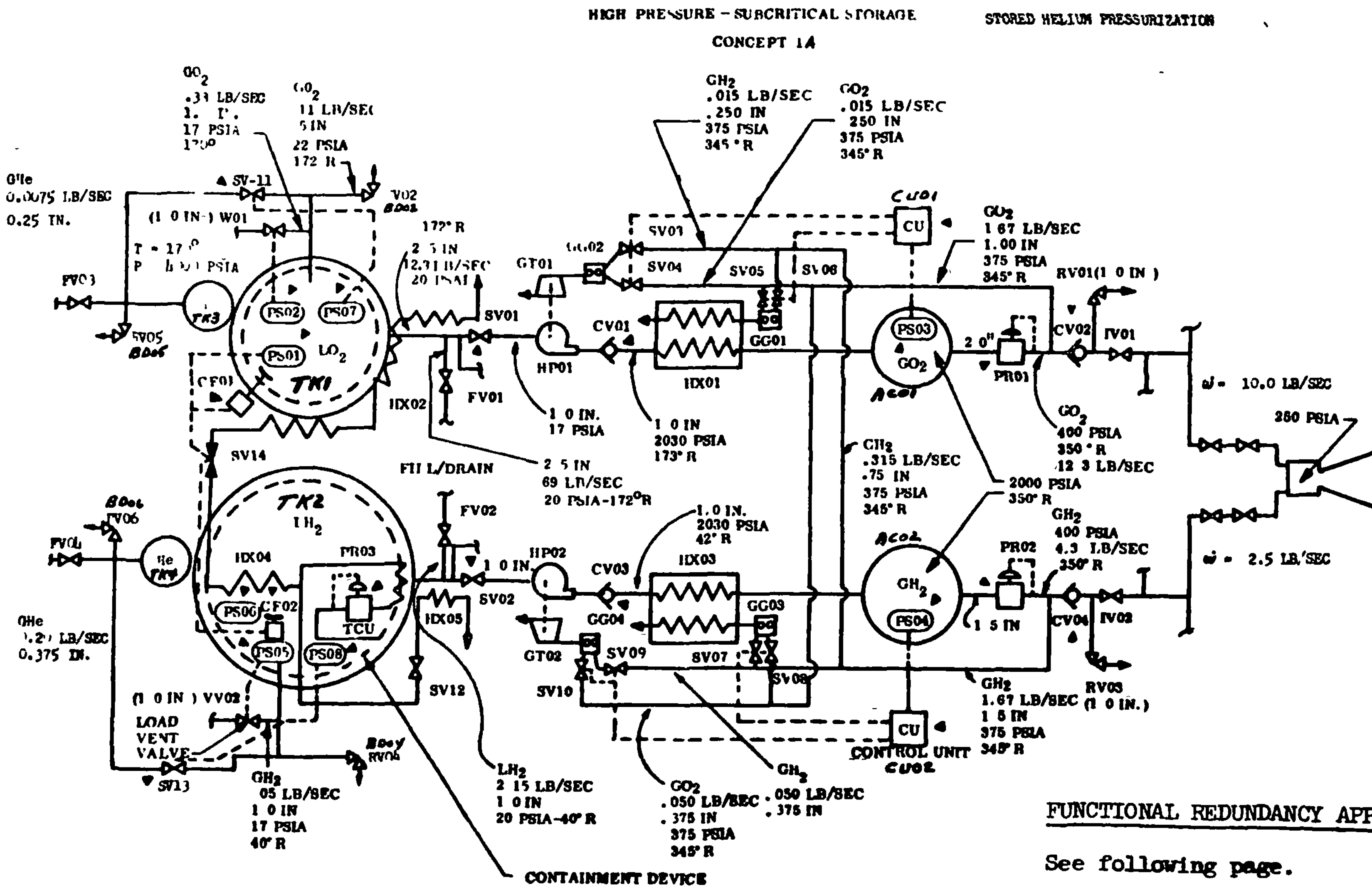

FUNCTIONAL REDUNDANCY APPRAISAL

See following page.

Fig.E-5 Attitude Control Propulsion System

ATTITUDE CONTROL PROPULSION SYSTEM

FUNCTIONAL REDUNDANCY APPRAISAL

All Check Valves: 2 in series

All Pressure Switches: 2 out of 3, voting.

SV01, SV02, SV11, SV13, SV14 : 2 in parallel, active for failure to open (Each valve).

CU01, CU02 : 2 in parallel, on standby for failure of primary unit.

CF01, CF02 : 2 in parallel, active for failure of either unit

PR03 : 2 in parallel, active for failure to regulate.

BD02, BD04 : Added units to keep stress off of relief valves until needed.

BD05, BD06 : Added units to keep stress off of relief valves until needed.

Fig. E-5 (cont'd)

FUNCTIONAL REDUNDANCY APPRAISAL

See following page.

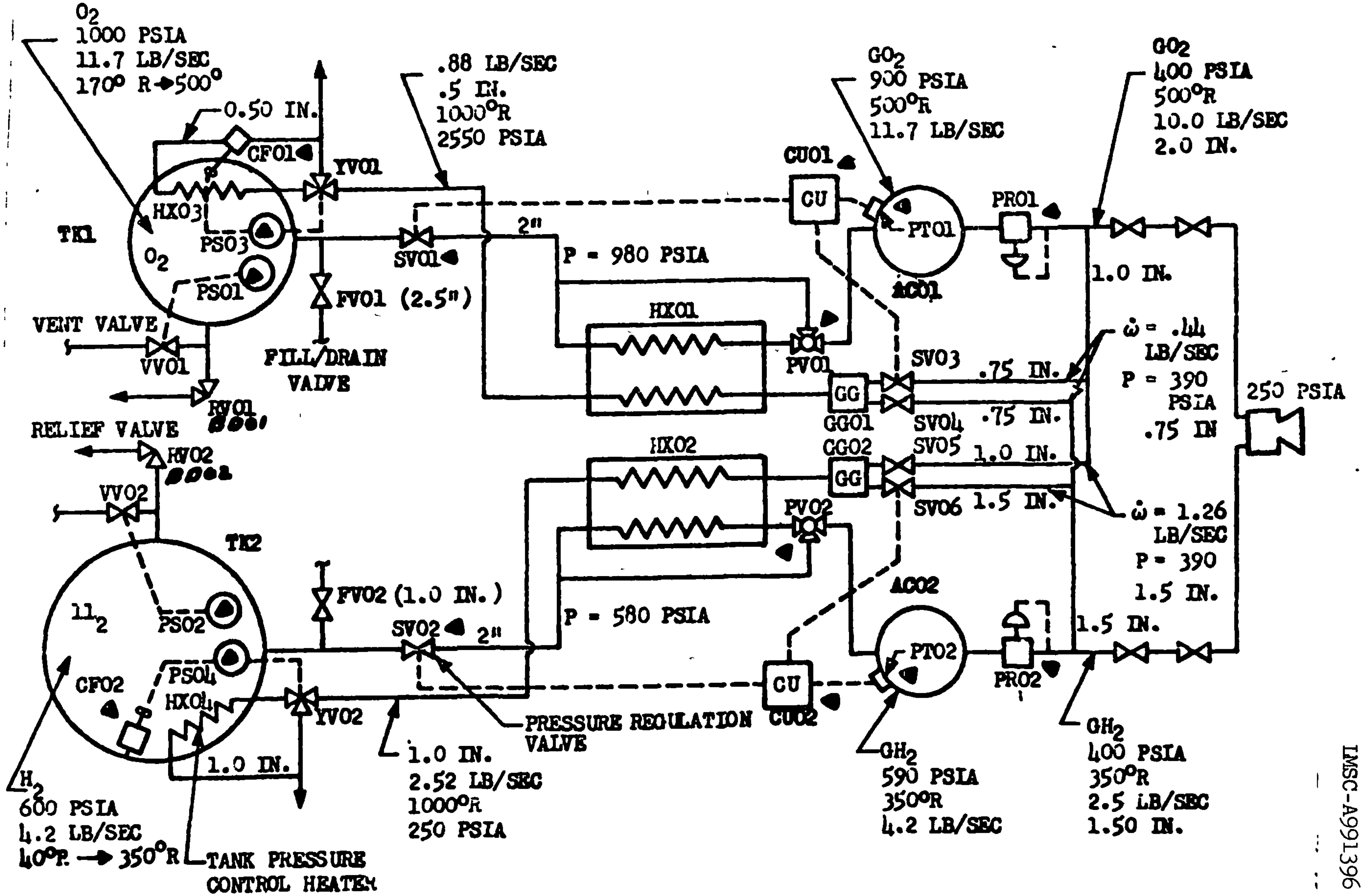

Fig. E-6 Attitude Control Propulsion System

ATTITUDE CONTROL PROPULSION SYSTEM (ACPS-2)

FUNCTIONAL REDUNDANCY APPRAISAL

All Pressure Switches : 2 out of 3, voting.

PT01 PT02	:	2 in parallel, one standby for failure of primary sensor.
CU01 CU02	:	2 in parallel, one standby for failure of primary unit.
PR01 PR02	:	2 in series, active for failure of primary unit to regulate.
SV01 SV02	:	2 in parallel, active for failure of valve to open.
CF01 CF02	:	2 parallel units, active for failure of either unit.
BD01 BD02	:	Added units to keep stress off of relief valve until needed.
PV01 PV02	:	Provide 2 series units such that failure of primary unit will be to flow through cold gas by-pass line, secondary unit will then modulate hot gas from line placed ahead of primary unit. (See sketch.)
TS01 TS02	:	Added units for providing temperature sensing to PV01 and PV02 mixing valve assemblies. Unless temperature sensors are built into PV units.

Fig. E-6 (cont'd)

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FUNCTIONAL REDUNDANT APPRAISAL

See following page.

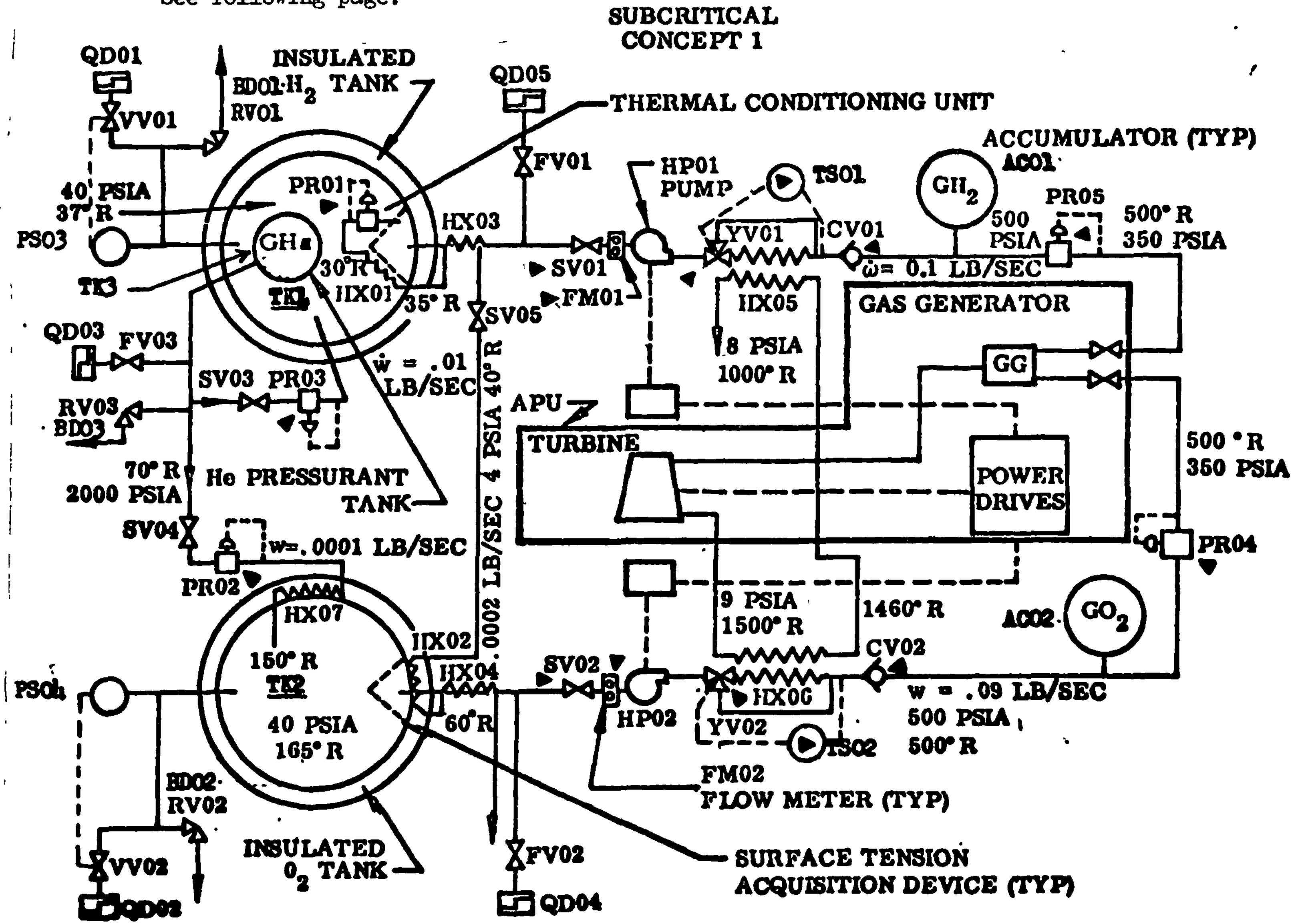

Fig. E-7 APU Supply System Surbcritical

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APU SUPPLY SUBCRITICAL SYSTEM

FUNCTIONAL REDUNDANCY APPRAISAL

BD01 BD02 BD03	:	Added units to relieve stress on relief valves until required for use. Provides protection in unpowered condition.
PS03 PS04	:	Added units to permit venting at preset tank vent pressure, provides protection during powered operations.
PR02 PR03 PR04 PR05	:	2 in series, active for failure of primary regulator. Primary unit fails open. May be arranged in cascade pressure drop if desired.
PR01	:	2 in parallel, active for failure to regulate in either unit.
SV01 SV02	:	2 in parallel, standby for failure of primary valve to open.
FM01 FM02	:	2 in series, active for failure of either unit.
YV01 YV02	:	2 in parallel, standby for failure of primary mixing valve to function. (See System 6)
CV01 CV02	:	2 in series, active for failure of either unit to seat.

Fig. E-7 (cont'd)

FUNCTIONAL REDUNDANCY APPRAISAL

See following page.

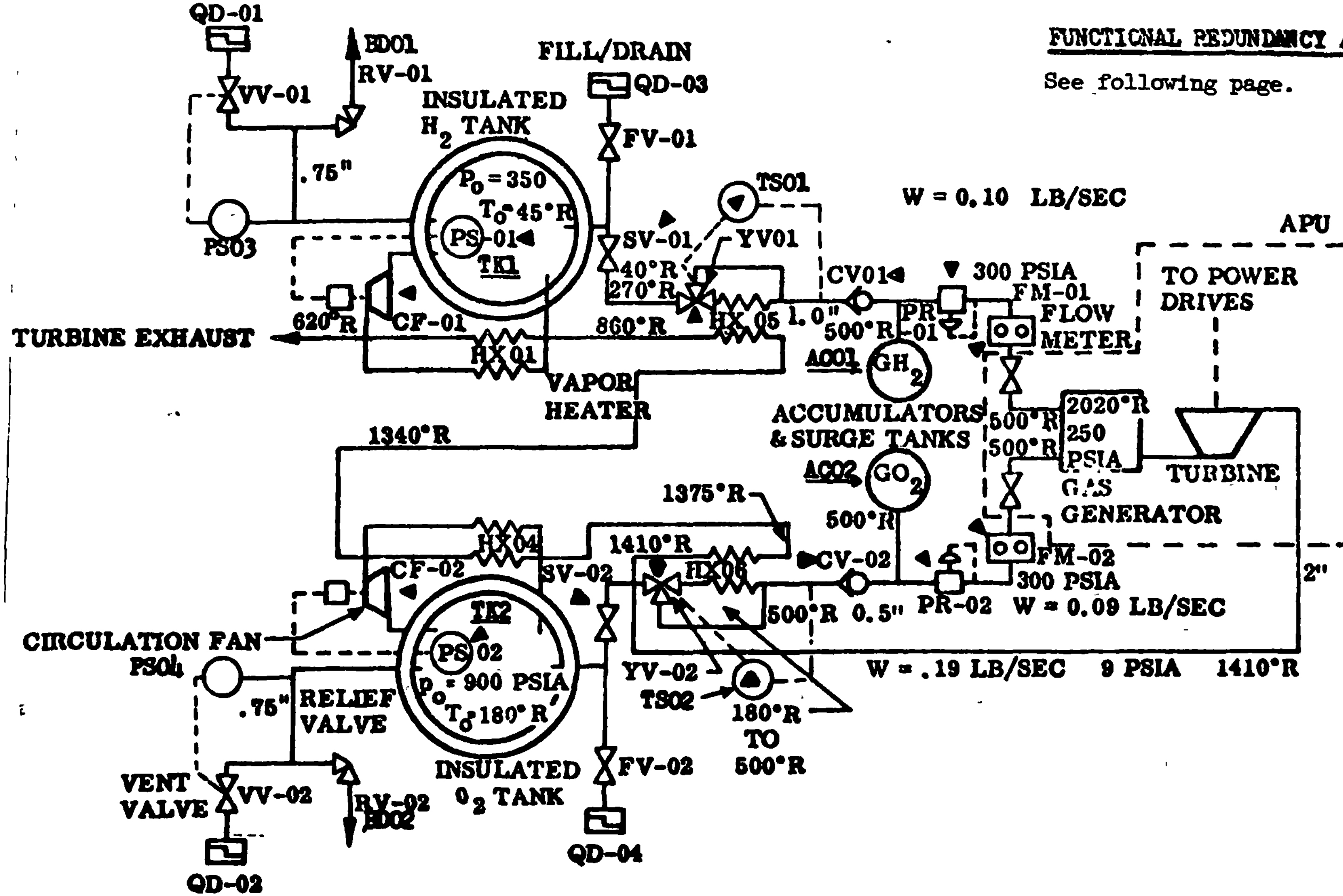


Fig. E-8 APU Supply System Supercritical

APU SUPPLY SUPERCRITICAL SYSTEM (APU-2)

FUNCTIONAL REDUNDANCY APPRAISAL

PS01, PS02	:	2 out of 3, voting
SV01, SV02	:	2 in parallel, one standby for failure of primary valve to open.
YV01, YV02	:	2 in parallel, one standby for failure of primary mixing valve to function.
TS01, TS02	:	2 in parallel, one standby for failure of primary sensor.
CV01, CV02	:	2 in series for failure of one to seat.
PR01, PR02	:	2 in series, active for failure of primary regulator to regulate. Primary unit fails open. May be arranged also in cascade pressure drop.
FM01, FM02	:	2 in series, active for failure of either unit.
CF01, CF02	:	2 in parallel, active for the failure of either unit.
BD01, BD02	:	Added units to relieve stress on relief valve until needed. Provides vent protection for unpowered condition.
PS03, PS04	:	Added units to permit venting at present tank vent input during powered operation. Non-redundant for low-duty cycle.

Fig. E-8 (cont'd)

FUNCTIONAL REDUNDANCY APPRAISAL

See following page.

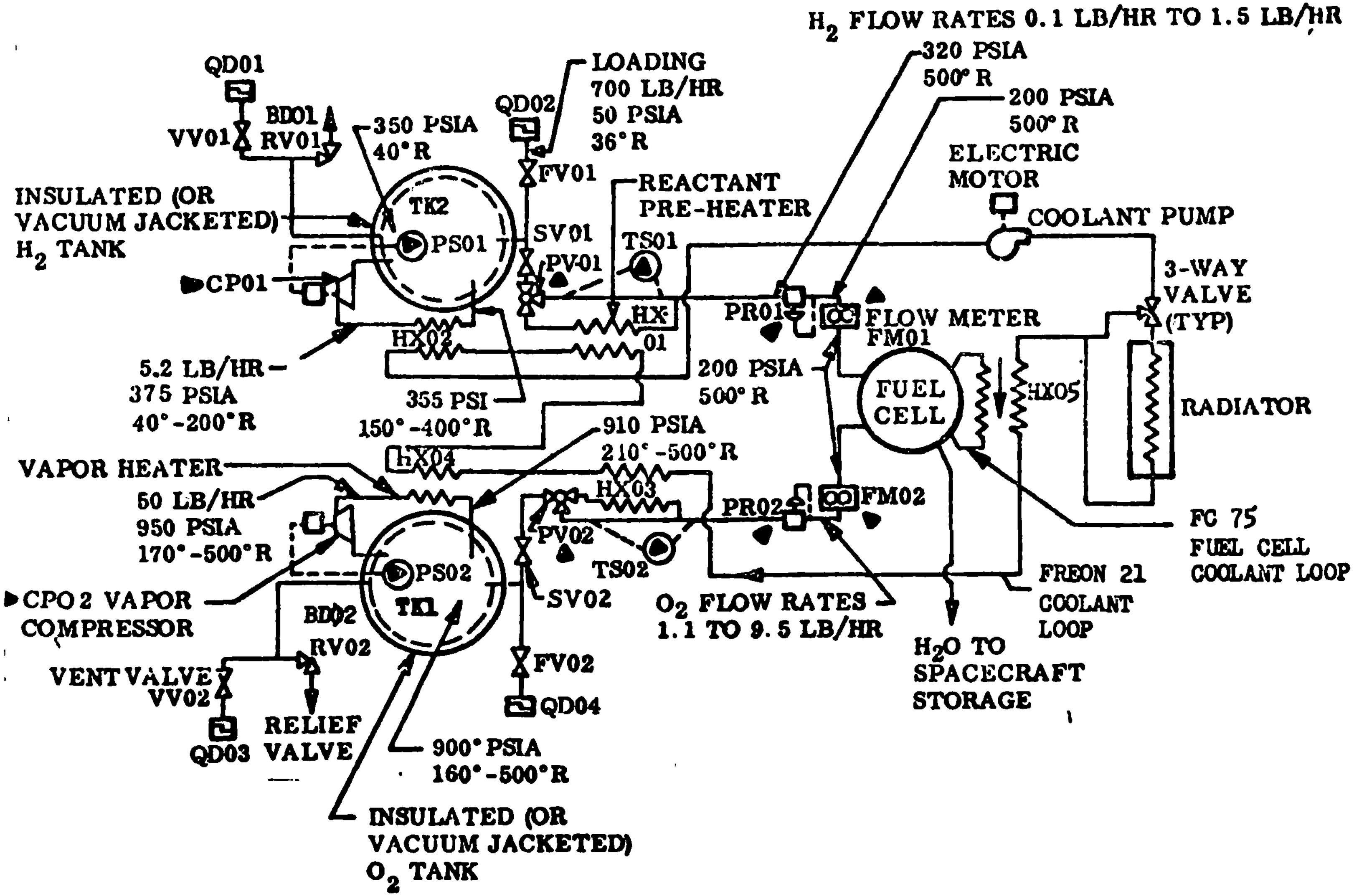


Fig. E-9 Fuel Cell Supply System Supercritical

FUEL CELL SUPPLY SUPERCRITICAL SYSTEM

FUNCTIONAL REDUNDANCY APPRAISAL

All Pressure Switches: 2 out of 3, voting.

CP01 / CP02	:	2 units in parallel, active for failure of either unit.
PR01 / PR02	:	2 units in series, active for failure of primary unit to regulate, first unit fails open.
FM01 / FM02	:	2 unit in series, active for failure of either unit.
TS01 / TS02	:	2 units in parallel, standby for failure of primary sensor.
PV01 / PV02	:	2 units in parallel, standby for failure of primary mixing valve. (As per in System 6.)

Fig. E-9 (cont'd)

FUNCTIONAL REDUNDANCY APPRAISAL

See following page

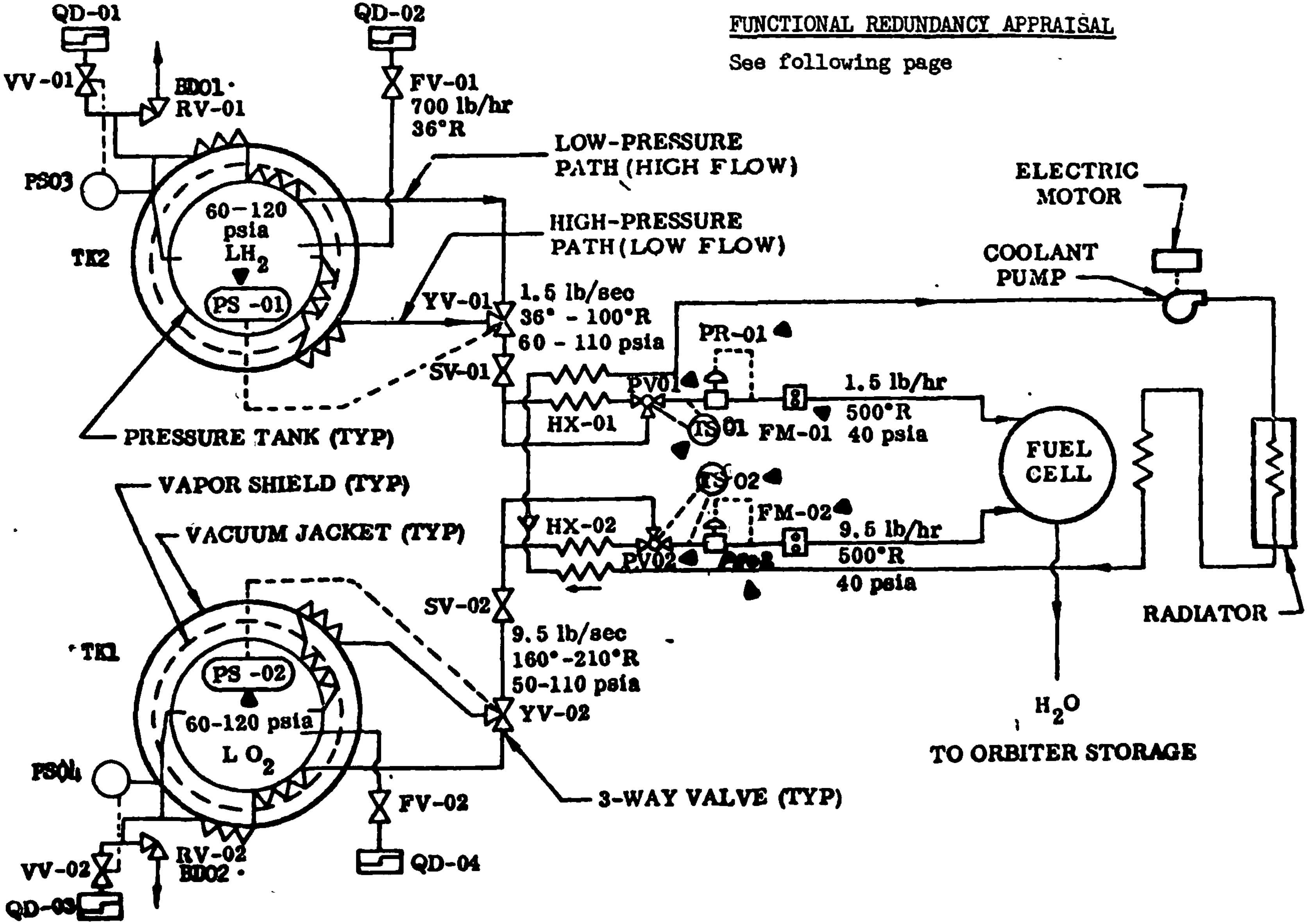


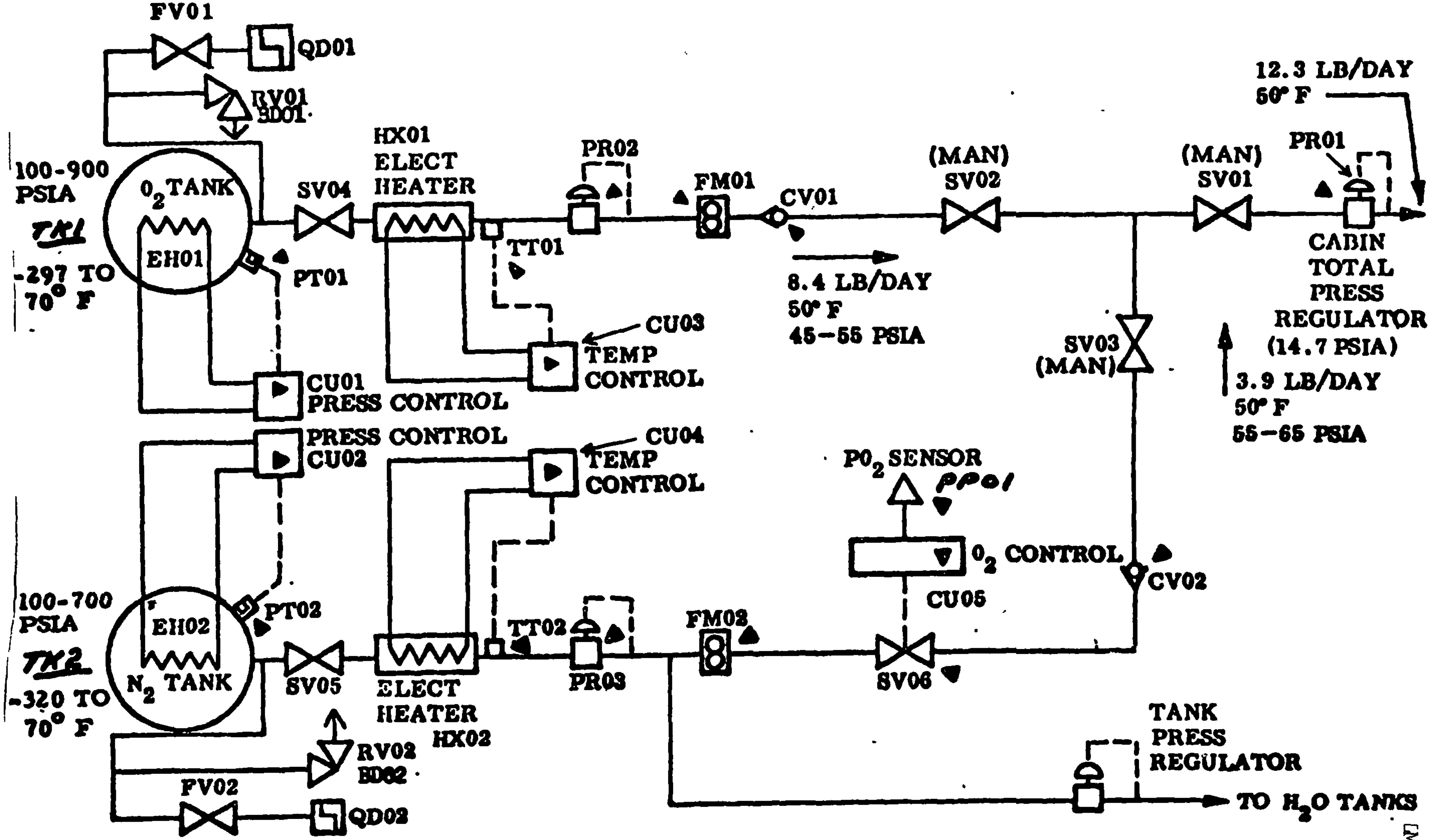
Fig. E-10 Fuel Cell Supply System Subcritical

FUEL CELL SUPPLY SUBCRITICAL SYSTEM

FUNCTIONAL REDUNDANCY APPRAISAL

PS01 PS02	:	2 out of 3, voting
PV01 PV02	:	2 in parallel, one standby for failure of primary unit. (As in System 6)
TS01 TS02	:	2 in parallel, one standby for failure of primary sensor
PR01 PR02	:	2 in series, active for failure to regulate by primary regulator. Primary unit to fail open. (May be cascade).
FM01 FM02	:	2 in series, active for failure of either unit.
BD01 BOD2	:	Added units to relieve stress on relief valve until needed. Protects tankage when units are unpowered.
PS03 PS04	:	Added units to permit venting when system is powered.

Fig. E-10 (cont'd)



<u>FUNCTIONAL REDUNDANCY APPRAISAL</u>

See following page.

Fig. E-11 EC/LSS-Gas Supply and Pressure Control System - Supercritical

EC/LSS-GAS SUPPLY AND PRESSURE CONTROL SYSTEM (SUPC)

FUNCTIONAL REDUNDANCY APPRAISAL

PT01 PT02	:	2 in parallel, standby for failure of primary transducer.
CU01 CU02 CU03 CU04 CU05	:	2 in parallel, standby for failure of primary controller unit
TT01 TT02	:	2 in parallel, standby for failure of primary transducer.
PR01 PR02 PR03	:	2 in series, active for failure of primary regulator to function. Primary unit fails open. May be arranged in cascade pressure-drop sequence if desired.
FM01 FM02	:	2 in series, active for the failure of either unit.
CV01	:	2 in series, active for the failure of either check valve to seat.
SV06	:	2 in parallel, standby for the failure of primary valve to open.
PP01	:	2 in parallel, active for the failure of either sensor to function. Extra PP01 units (plug-in) should be available in cabin as LRU's.

Fig. E-11 (cont'd)

FUNCTIONAL REDUNDANCY APPRAISAL

See following page.

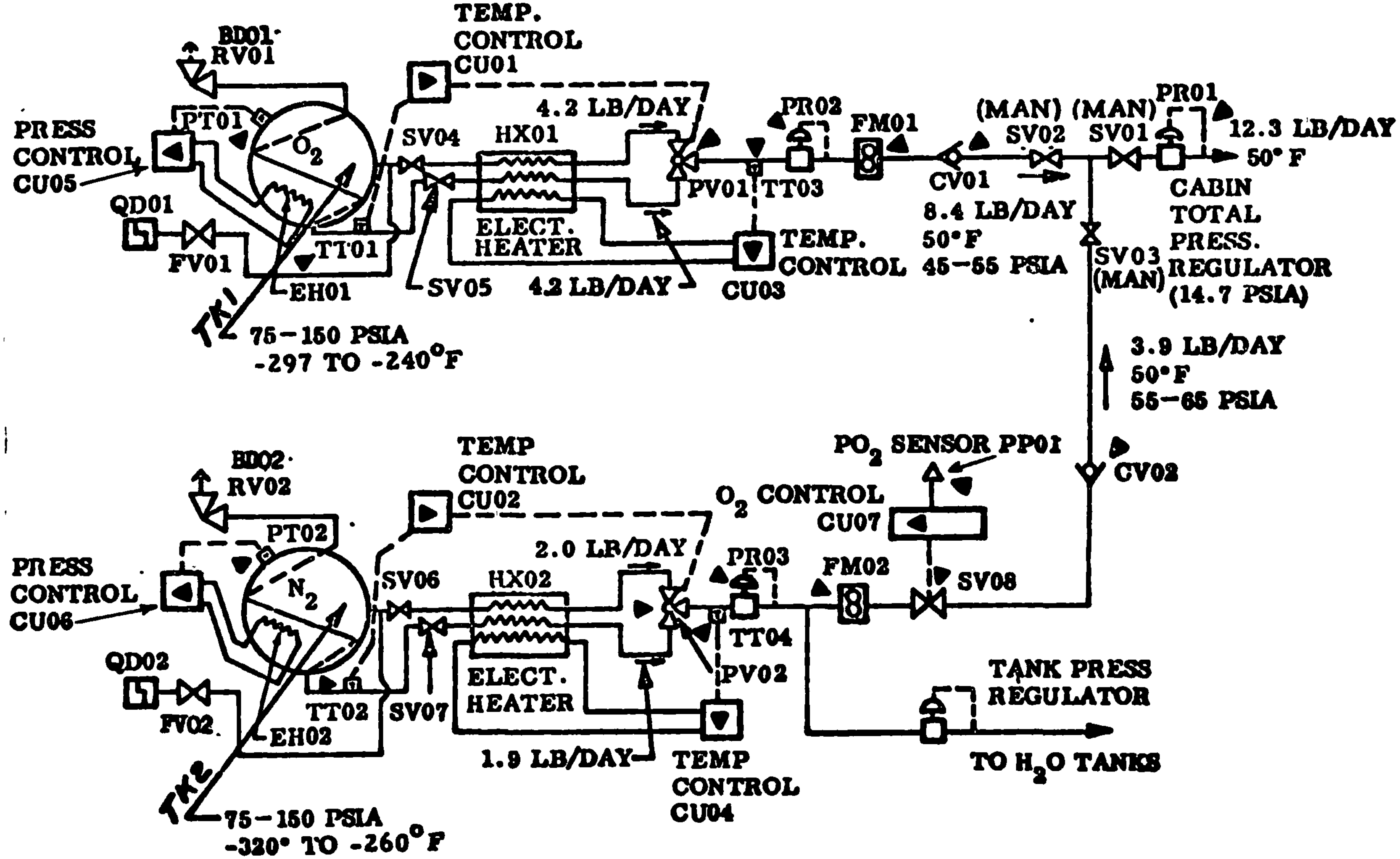


Fig. E-12 EC/LSS-Gas Supply and Pressure Control System - Subcritical

EC/LSS - GAS SUPPLY AND PRESSURE CONTROL SYSTEM

FUNCTIONAL REDUNDANCY APPRAISAL

PT01 PT02	:	2 in parallel, standby for failure of primary transducer.
CU01 CU02 CU03 CU04 CU05 CU06 CU07	:	2 in parallel, standby for failure of primary control unit.
TT01 TT02 TT03 TT04	:	2 in parallel, standby for failure of the primary transducer.
PV01 PV02	:	2 in parallel, standby for the failure of the primary mixing valve. (See System 6)
PR01 PR02 PR03	:	2 in series, active for the failure of primary regulator to function. Primary regulator fails open. May be arranged in cascade pressure-drop sequence if desired.
FM01 FM02	:	2 in series, active for the failure of either unit.
CV01 CV02	:	2 in series, active for failure of either check valve to seat.
SV08	:	2 in parallel, standby for failure of primary valve to open.
PP01	:	2 in parallel, active for the failure of either sensor to function. Extra PP01 units (plug-in) should be available in cabin as LRU's.
BD01 BD02	:	Added units to relieve stress on relief valve until needed.

Fig. E-12 (cont'd)

COLD HELIUM - CONCEPT 1

FUNCTIONAL REDUNDANT APPRAISAL

See following page.

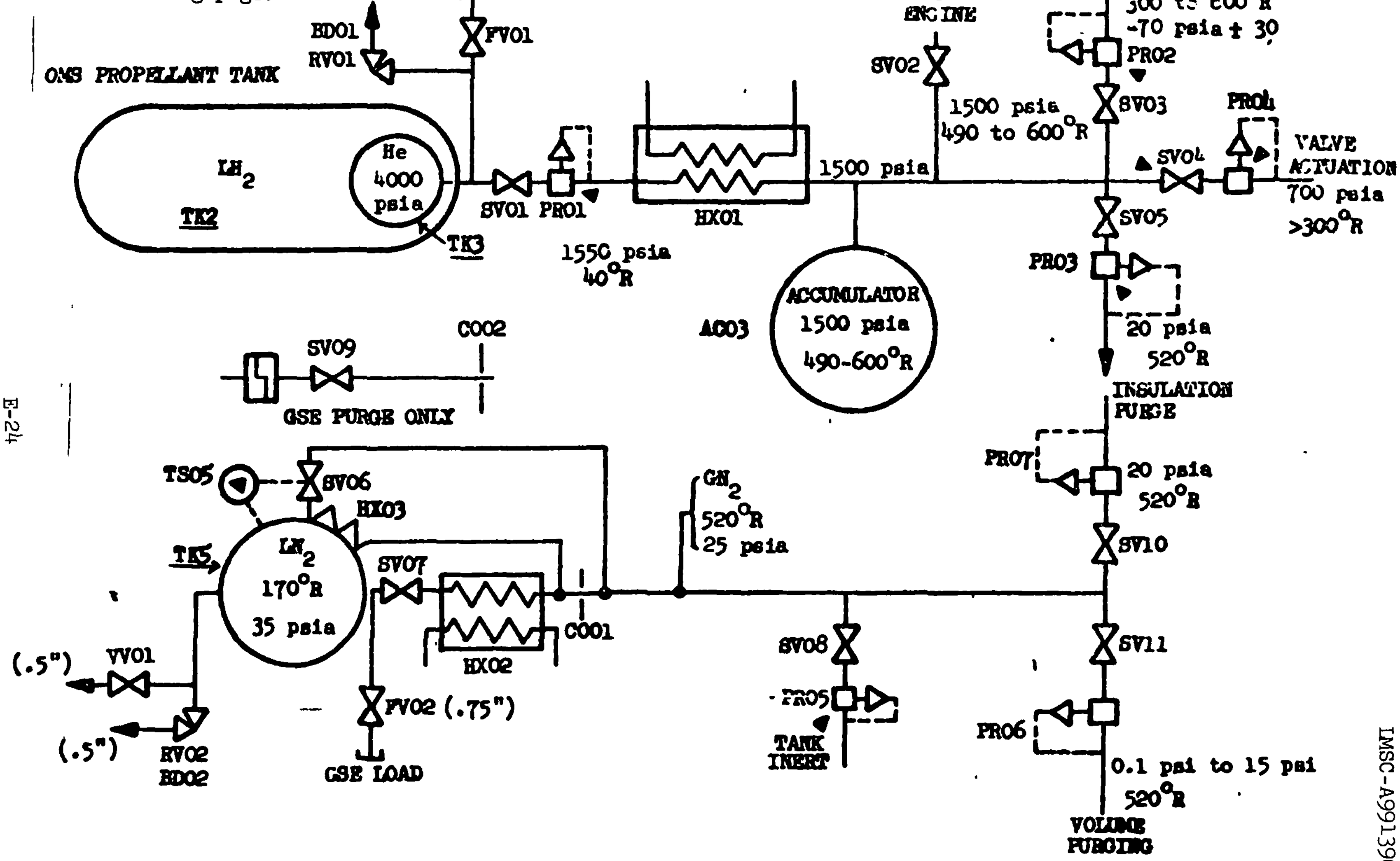


Fig. E-13 Purge, Inerting, Pneumatic System

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PURGE, INERTING, PNEUMATIC SYSTEM (PIPS-1)

FUNCTIONAL REDUNDANCY APPRAISAL

PR01 PR02 PR03 PR04 PR05	:	2 in series, active for failure of primary regulator to function. Primary unit fails open. May be arranged in cascade pressure drop sequence if desired.
SV04	:	2 in parallel, standby for failure of primary valve to open.
TS05	:	2 in parallel, standby for failure of primary sensor.

Fig. E-13 (cont'd)

SUPERCRITICAL N_2, AMBIENT HIGH PRESSURE He - C2

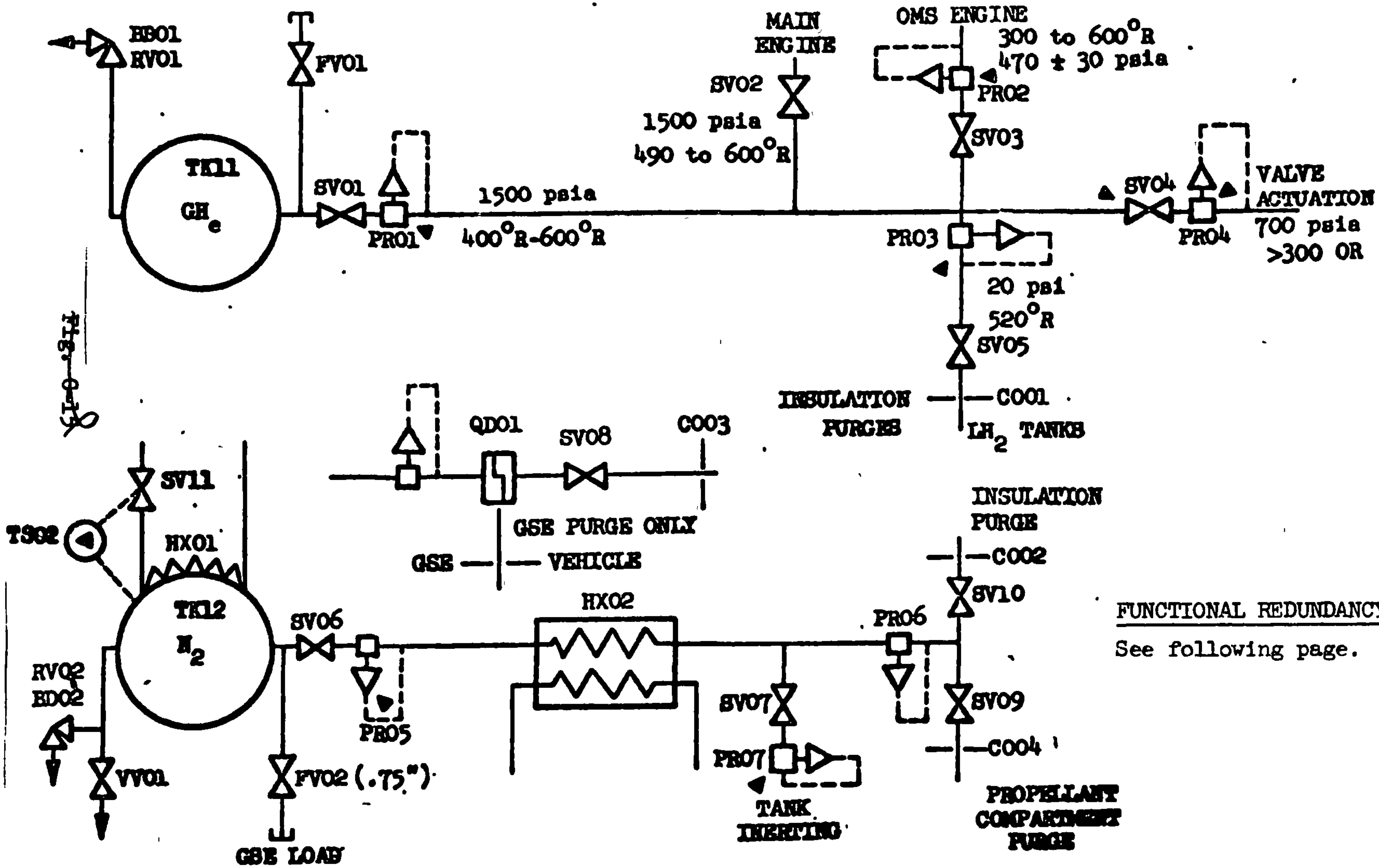

Fig. E-14 Purge, Inerting, Pneumatic System

FUNCTIONAL REDUNDANCY APPRAISAL

See following page.

PURGE, INERTING, PNEUMATIC SYSTEM

FUNCTIONAL REDUNDANCY APPRAISAL

PR01 PR02 PR03 PR04 PR05 PR07	:	2 in series, active for failure of primary regulator to function. Primary unit fails open. May be arranged in cascade pressure drop sequence if so desired.
SV04	:	2 in parallel, standby for failure of primary valve to open.
TS02	:	2 in parallel, standby for failure of primary sensor.

Fig. E-14 (cont'd)

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